# SOURCE TRACKING PROTOCOL DEVELOPMENT PROJECT

Clean Beaches Grant Agreement 07-583-550-2

FINAL GRANT REPORT

City of Santa Barbara

Creeks Division

August 20, 2012

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# CONTENTS



NOTE: This Report and all Appendices are available online at
http://www.santabarbaraca.gov/Resident/Community/Creeks/Reports_and_Studies.htm

## List of Figures

## LIST OF TABLES

# Problem Statement & Relevant Issues

## Beach Warnings

The main water quality problem that the Source Tracking Protocol Development Project (Project) addresses is frequent beach warnings at California beaches due to high levels of indicator bacteria discharging from creeks and storm drains. The Project is located in Santa Barbara, CA, a city of approximately 90,000 people located in the County of Santa Barbara (Figure 1). Four beaches located in the City of Santa Barbara (City) are listed as impaired on the 2010 Clean Water Act Section 303(d) List of Impaired Waterbodies (Figure 2, Table 1) for fecal indicator bacteria (FIB) that are intended to signify contamination with pathogens. Several creeks discharging at the beaches are also listed as Impaired Waterbodies (Table 1). Two beaches, Arroyo Burro and East Beach at Mission Creek, have had periods of frequent beach warnings according to beach testing mandated in State Assembly Bill 411 (AB411; Table 2) during AB411 dates (April 1 – October 31 each year). Additionally, both beaches have been listed on Heal the Bay's list of "Beach Bummers" in past years.


**FIGURE 1. PROJECT LOCATION IN SANTA BARBARA, CA.**

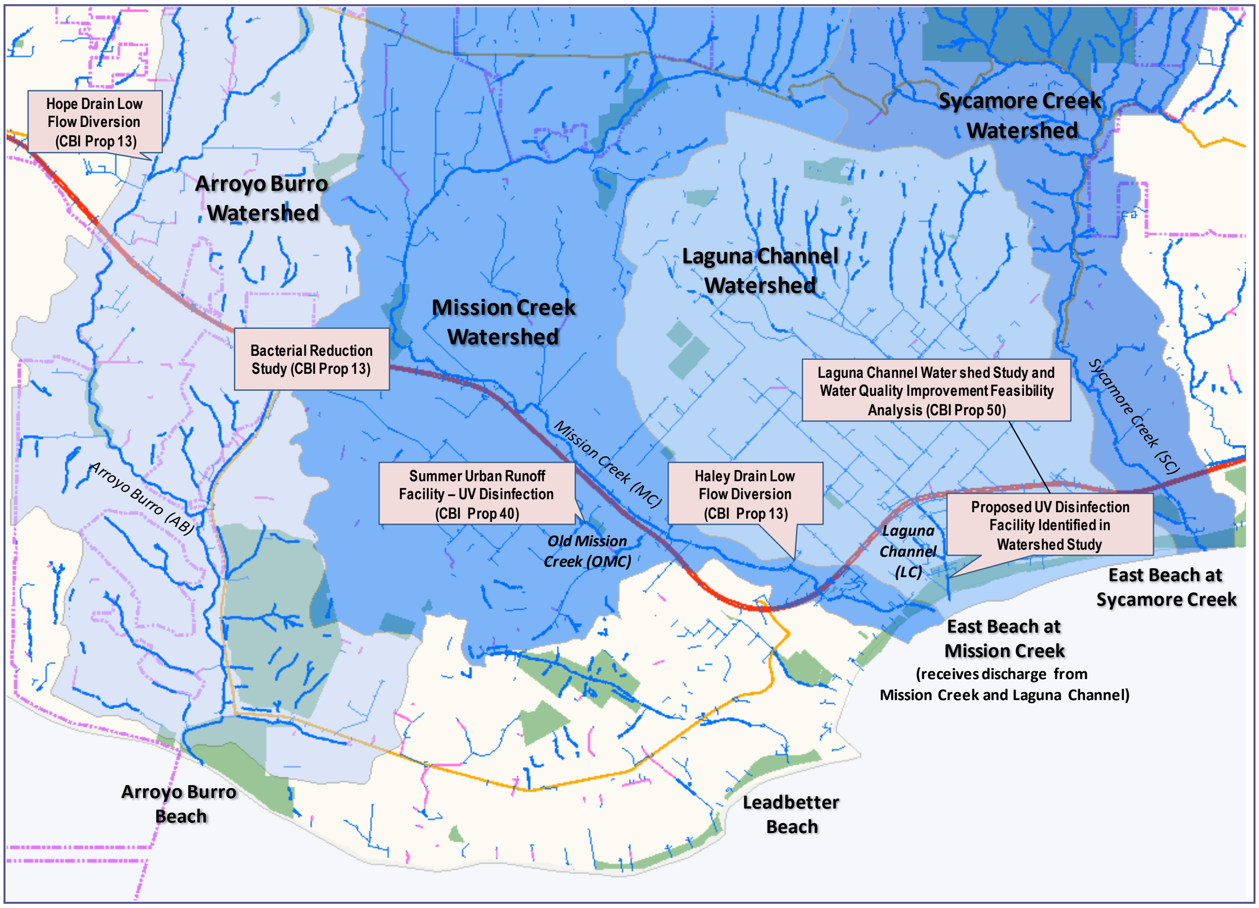



**FIGURE 2. AB411 BEACHES, CREEKS, STORM DRAIN PIPES, WATERSHED BOUNDARIES, AND CBI-FUNDED PROJECTS LOCATED IN THE CITY OF SANTA BARBARA.**

**TABLE 1. IMPAIRED BEACHES AND ASSOCIATED WATERBODIES, 2010 CLEAN WATER ACT SECTION 303(D) LISTINGS.**

| Impaired Beach | Pathogen Related Listings | Waterbody Discharging to Beach (Impairment) |
|---|---|---|
| **East Beach at Mission Creek** | Enterococcus, Fecal Coliform, Total Coliform | Mission Creek (E. coli, Fecal Coliform)<br>Laguna Channel (not assessed) |
| **Arroyo Burro Beach** | Enterococcus, Total Coliform | Arroyo Burro Creek (E. coli, Fecal Coliform) |
| **Leadbetter Beach** | Total Coliform | Honda Creek (not assessed) |
| **East Beach at Sycamore Creek** | Enterococcus | Sycamore Creek (Fecal Coliform) |

**TABLE 2. BEACH WARNINGS AT IMPAIRED BEACHES IN SANTA BARBARA.**

| AB411 Year | Arroyo Burro Beach | East Beach at Mission Creek |
|---|---|---|
| **1999** | 6 | 5 |
| **2000** | 16 | 5 |
| **2001** | 5 | 6 |
| **2002** | 8 | 7 |
| **2003** | 3 | 1 |
| **2004** | 7 | 6 |
| **2005** | 11 | 13 |
| **2006** | 15 | 16 |
| **2007** | 6 | 5 |
| **2008** | 12 | 3 |
| **2009** | 5 | 1 |

A statistical analysis of beach warnings completed by the City using AB411 monitoring data showed that exceedances of AB411 criteria are far more frequent when the creeks and associated lagoons at both of these beaches are open and flowing to the ocean, compared to when they are closed, illustrating the importance of water quality in coastal creeks and the storm drains discharging to them (Table 3).

**TABLE 3. EFFECT OF LAGOON STATUS (OPEN/CLOSED) ON INDICATOR BACTERIA LEVELS AND EXCEEDANCE FREQUENCY**

| Lagoon Open and Closed (Dry Days) 2001-2009 | | | | | |
|---|---|---|---|---|---|
| | | **All Beaches** | **AB** | **MC E Beach** | **SC E Beach** |
| **Enterococcus** | **Open** | Median: 20, n=522<br>% exc. 15.90 | Median: ≤10, n=282<br>% exc. 8.87 | Median: 31, n=176<br>% exc. 25.57 | Median: 30, n=64<br>% exc. 20.31 |
| | | *** | ** | *** | *** |
| | **Closed** | Median: ≤10, n=627<br>% exc. 4.63 | Median: ≤10, n=102<br>% exc. 5.88 | Median: ≤10, n=207<br>% exc. 5.31 | Median: ≤10, n=318<br>% exc. 3.77 |
| **Fecal Coliform** | **Open** | Median: 41, n=518<br>% exc. 8.88 | Median: 31, n=282<br>% exc. 6.03 | Median: 74, n=173<br>% exc. 14.45 | Median: 41, n=63<br>% exc. 6.35 |
| | | *** | *** | *** | *** |
| | **Closed** | Median: ≤10, n=603<br>% exc. 1.00 | Median: ≤10, n=102<br>% exc. 1.96 | Median: 20, n=196<br>% exc. 1.53 | Median: ≤10, n=305<br>% exc. 0.33 |
| **Total Coliform** | **Open** | Median: 591, n=518<br>% exc. 9.65 | Median: 666, n=282<br>% exc. 9.57 | Median: 714, n=173<br>% exc. 12.72 | Median: 350, n=63<br>% exc. 1.59 |
| | | *** | *** | *** | *** |
| | **Closed** | Median: 41, n=603<br>% exc. 0.33 | Median: 57, n=102<br>% exc. 0.00 | Median: 74, n=196<br>% exc. 0.51 | Median: 20, n=305<br>% exc. 0.33 |
| Note: Medians are in MPN/100ml | | | | | |
| * <0.05 **<0.01 ***<0.001 from the Kruskall-Wallis Test | | | | | |
| Note: No information available for Leadbetter beach | | | | | |

The City of Santa Barbara has taken an aggressive approach to reducing indictor bacteria levels and beach warnings by installing capital projects such as low-flow storm drain diversions and an ultraviolet (UV) disinfection project (with funding from the Proposition 13 and Proposition 40 Clean Beaches Grant

Program; Figure 2). Concurrent with the capital program, the City continues to search for sources of indicator bacterial contamination.

## Sources of Indicator Bacteria

Fecal indicator bacteria can come from human waste and animal feces, but they can also grow in decaying plant material and even on storm drain surfaces, gutters, kelp, and sand grains. Indicator bacteria growing in the environment are unlikely to pose health risks to humans, and the risk associated with animal fecal sources is unknown. The USEPA reports that there has never been a documented outbreak of animal-associated illness among swimmers at marine beaches, despite frequently high levels of fecal indicator bacteria in some locations (USEPA 2011). The vast majority of fecal indicator bacteria are not themselves pathogens (microbes that cause illness). Among types of fecal contamination at coastal, urban beaches, untreated human waste has the greatest potential to sicken beach goers. Most illnesses would likely cause mild-to-moderate gastrointestinal (GI) problems, but untreated waste also has the potential to transmit more harmful pathogens.

In order to determine the sources fecal indicator bacteria found in Santa Barbara creeks and beaches, several years ago the City partnered with Dr. Patricia Holden at the University of California, Santa Barbara (UCSB), whose research group recruited and tested cutting edge microbial markers, and developed other approaches, to investigate sources of indicator bacteria. Results from this early research showed that some storm drain outfalls in Santa Barbara displayed consistent DNA-based signals of human waste (Sercu et al. 2009).

With support of its Creeks Restoration and Water Quality Improvement Program Citizen Advisory Committee, the City decided to prioritize the goal of locating and eliminating human waste contributions to fecal indicator bacteria loads due to the potential associated health risks. However, despite substantial effort, tracking signals up storm drain networks to the points of input remained impossible.

## Sources of Human Waste to Storm Drains, Creeks, and Beaches

There are several potential sources of untreated human waste in creeks, beaches, and storm drains, including visible and invisible sources.

**Visible sources** include:

- Use of creek banks and nearby swales as latrines.
- Homeless encampments.
- Recreational vehicle dumping or leaking.
- Dumping of “chamber pots” into storm drains and creeks in overcrowded residential.
- Late night use of parking lots, sidewalks, planters, and stairwells that are later hosed into storm drains.

Visible sources can be located and removed. Repeated incidents can be addressed with by providing outreach, enforcement, restrooms, and barriers to creek access.

**Invisible sources** include sewage discharge to storm drains via direct and indirect illicit connections (Figure 3). *Direct connections* refer to intentional or accidental connections to the storm drain network. The picture below shows the confusing array of underground pipe layouts in urban settings. A plumbing contractor called in for repairs would likely not have the benefit of a large excavation and may mistake a storm drain for a sanitary sewer pipe. Most direct connections containing human waste are first identified by observing toilet paper in manholes, gutters, or storm drain outlets to creeks. *Indirect connections* refer to leaking sewer lines – laterals and mainlines – that cause untreated wastewater to reach storm drains. This process is also called exfiltration from sewer lines or infiltration to storm drain lines. The USEPA estimates that up to 10% of wastewater flow can be lost to exfiltration where older pipes are located above groundwater levels (USEPA 2000). Locating indirect connections was a major focus of this project.

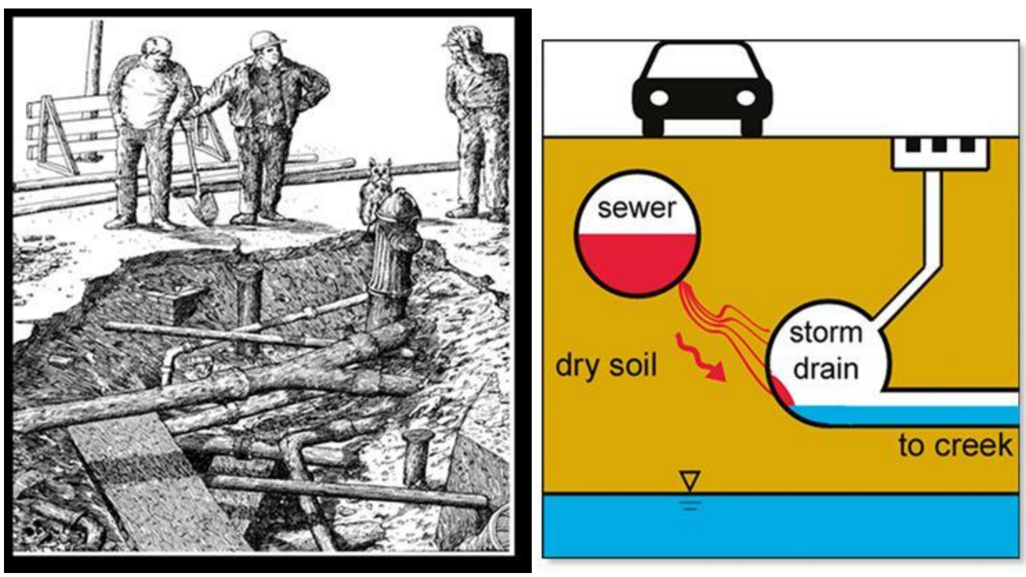


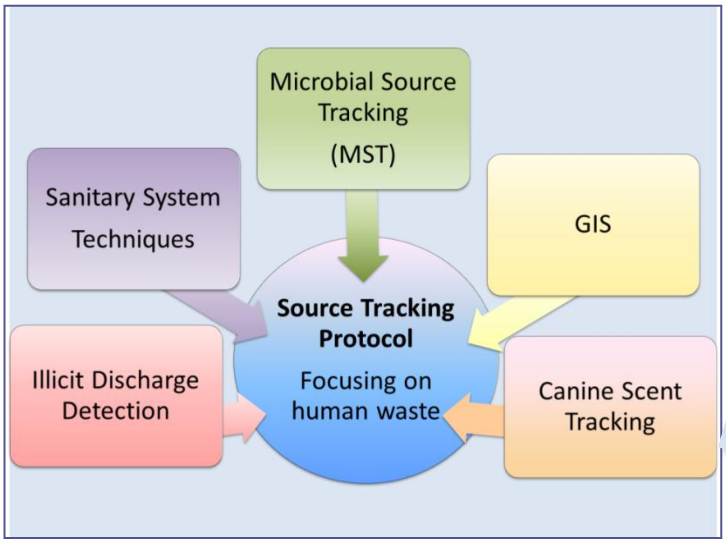

**FIGURE 3. ILLUSTRATIONS OF POTENTIAL DIRECT (LEFT) AND INDIRECT (RIGHT) CONNECTIONS BETWEEN SEWER PIPES AND STORM DRAINS.**

## PROJECT GOALS

**The short term goal** of the research described here is to identify where, when, and how human waste is transported to storm drains, creeks, and beaches in Santa Barbara. By combining molecular microbiology with engineering tools, the research proposed to provide an urban detective toolkit that is needed to solve sustained contamination problems. The aim is to provide protocols for coastal managers throughout California to use for conducting source investigations of storm drains that produce exceedences of AB411 indicator bacteria standards (Figure 4). Tools include:

- Human-specific waste markers
- Community microbial approach, e.g. Phylochip Microarray

- Flow gauges and autosamplers
- Non Human-Specific Chemistry
- Canine Scent Tracking
- Televising of Storm Drains using Closed Circuit Television Cameras (CCTV)
- Basic Dye Tests
- Smoke Tests
- Dye with Rhodamine Wastewater Tracer and Probe
- Geographic Information Systems (GIS)



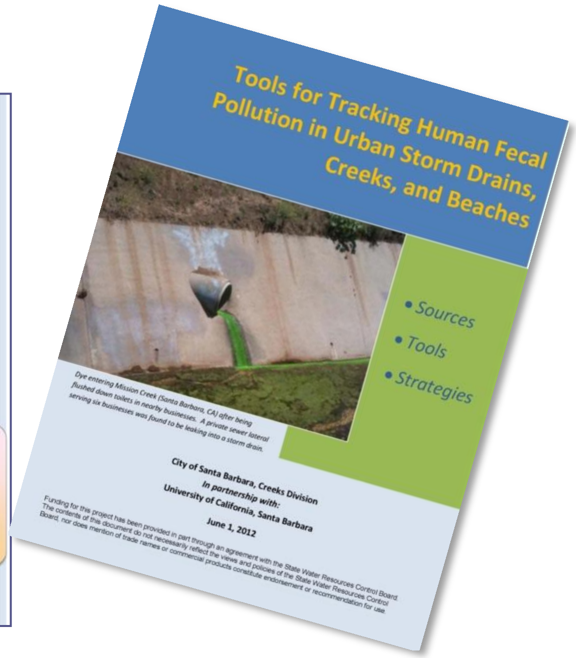




**FIGURE 4. TESTING AND INTEGRATING TOOLS AND PRODUCING AN ACCESSIBLE PROTOCOL GUIDE (APPENDIX A) ARE THE SHORT TERM GOALS OF THIS PROJECT.**

**The long-term goal** of this research is to contribute towards the reduction of human-waste indicator bacteria and improve recreational contact (REC-1 and REC-2) of receiving waters, including creeks, lagoons, and oceans throughout California (Figure 5). An additional goal is to meet the mandate in AB538 for a source-tracking protocol for coastal managers to be able to reduce the number of beach warnings, especially sustained warnings of human waste/sewage origins that are indicative of a real health risk (Figure 4)..


**FIGURE 5. REDUCING BEACH WARNINGS IS THE LONG TERM GOALS OF THIS PROJECT.**

# PROJECT DESCRIPTION

## PROJECT TYPE

Clean Beaches Grant Program Research Project

## PROJECT COSTS

The project was budgeted accurately and all funds were spent as in Table 4. All funds were derived from the Proposition 50 Clean Beaches Initiative Grant Program.

**TABLE 4. PROJECT COSTS**

| Item | Projected Cost | Actual Cost | % Grant Funds Spent |
|---|---|---|---|
| **Personnel Costs** | $55,791 | $55,791 | 100% |
| **Equipment** | $60,000 | $60,000 | 100% |
| **Professional Services** | $361,489 | $361,489 | 100% |

During the freeze in State grant funding during the project, the Water Environment Research Foundation funded the City, UCSB, and Environmental Canine Services to conduct related source tracking work. In addition, Dr. Holden has received for the Clean Beaches Initiative Source Identification Protocol Project, based partly on the work presented here. She has also received private funding for a new project, Water in the Urban Environment, to tackle contamination of shallow groundwater, from sewage and other sources. The City also completed work on the Proposition 50 Clean Beaches Initiative Grant Program project Laguna Watershed Study and Water Quality Improvement Feasibility Analysis.

## PARTNERS INVOLVED

University of California, Santa Barbara (Dr. Patricia Holden)

## Project Summary

The following summary provides an overview of the project approach, methods, results, and conclusions. Frequent references are made to the main products of this research, which are located in the Appendices:

1. City of Santa Barbara, 2012. Tools for Tracking Human Fecal Pollution in Urban Storm Drains, Creeks, and Beaches. City of Santa Barbara, 2012 (Appendix A)
2. Holden, 2011. UCSB Final Report. (Appendix B)
3. Comprehensive Investigation of Sewage Infiltration to Storm Drains Using GIS, CCTV, and Dye Studies. (Appendix C)

In addition, literature references are provided in the References section below. The Executive Summary of the Final Grant Report for the Canine Source Tracking Project is provided in Appendix D. Copies of peer-reviewed articles arising from this Project are included in Appendix E.

### Approach and Methods

The City of Santa Barbara Creeks Division, in partnership with the University of California, Santa Barbara (UCSB, with Dr. Patricia Holden) performed this research project to determine the origins fecal indicator bacteria (FIB) associated with human fecal pollution (sewage) in storm drains that discharge to coastal creeks flowing to Santa Barbara beaches. At the onset of the project, the City awarded a contract to UCSB to perform the majority of the water sampling, laboratory analysis, and methods development. The overall goals were to determine origins of sewage contamination in storm drains during dry weather, and to compile a protocol for other communities to use for similar source tracking purposes, based on the results of this research. Specific tasks included:

- Select and purchase field and lab equipment.
- Develop detailed sampling plans for field investigation.
- Conduct field sampling over two (2) AB411 Seasons.
- Perform laboratory analysis of field samples.
- Perform data analysis.
- Develop GIS tools for visualizing and analyzing source tracking and sanitary survey investigation.
- Develop a “Source Tracking Protocol” for coastal managers.

At the project onset, previous results from source tracking work, including the Laguna Watershed Study, funded by a Clean Beaches Initiative Proposition 50 implementation grant, was used to select target areas for this Project. Two main areas, the Haley Drain area and the Nopal Storm Drain area, were selected for investigation of sewage infiltration to storm drains, as described in the Monitoring Plan for the Project (Figure 6). As discussed in the Monitoring Plan, other sites were to be chosen based on early results. The method proposed to test for exfiltration of sewage and infiltration to storm drains was based on measuring flow losses in sanitary sewer pipes and flow increases in nearby, parallel storm drains. This type method has been used successfully in certain locations with long stretches of parallel pipes (e.g. Rieckermann et al. 2005).

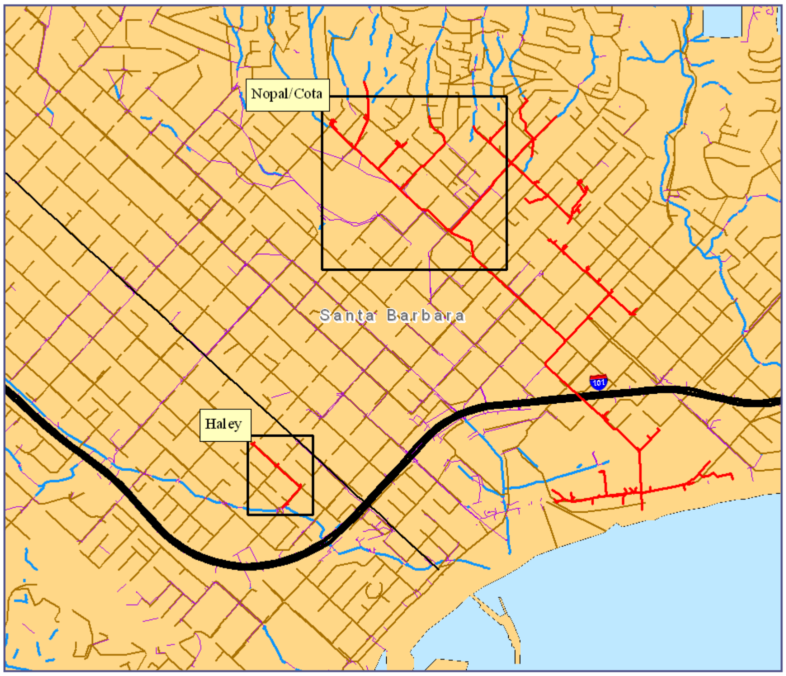



**FIGURE 6. FIELD SAMPLING TARGET AREAS AT PROJECT ONSET.**

During the period of this Project a complementary grant was obtained from the Water Environment Research Foundation to conduct canine scent tracking to support source tracking efforts. The use of the world's only sewage sniffing dogs was complementary to the technical and laboratory tools funded in this Project. The Executive Summary of the Final Report for the project, funded by the Water Environment Research Foundation, is provided in Appendix D. A grant amendment was approved by the State to complete a Comprehensive Storm Drain Televising and Dye Studies (Appendix C).

Two factors led to a change in the sampling approach. First, surprising results were obtained from the Haley Drain area, when samples from the drain did not test positive for human waste markers. Second, an alternative approach to revealing sewage infiltration was developed. The need for a new method was based on the realization that the proposed method would not be sensitive enough to detect infiltration. Specifically, results from flow gauges deployed in storm drains during the Laguna Watershed Study suggested that variability in flow, along with measurement variability, would preclude the high resolution needed to detect infiltration to the storm drain using the proposed flow differencing method. Additionally, the relatively short stretches of pipe that were suspected of leaking would not provide a large enough increase or decrease to be detected above background noise. Therefore, work was focused on the Nopal Drain area, and an innovative dye testing approach was developed for testing infiltration. Additional tools for investigation included the use of GIS for displaying spatial, multiparameter water quality data and GIS modeling of target locations for testing for infiltration.

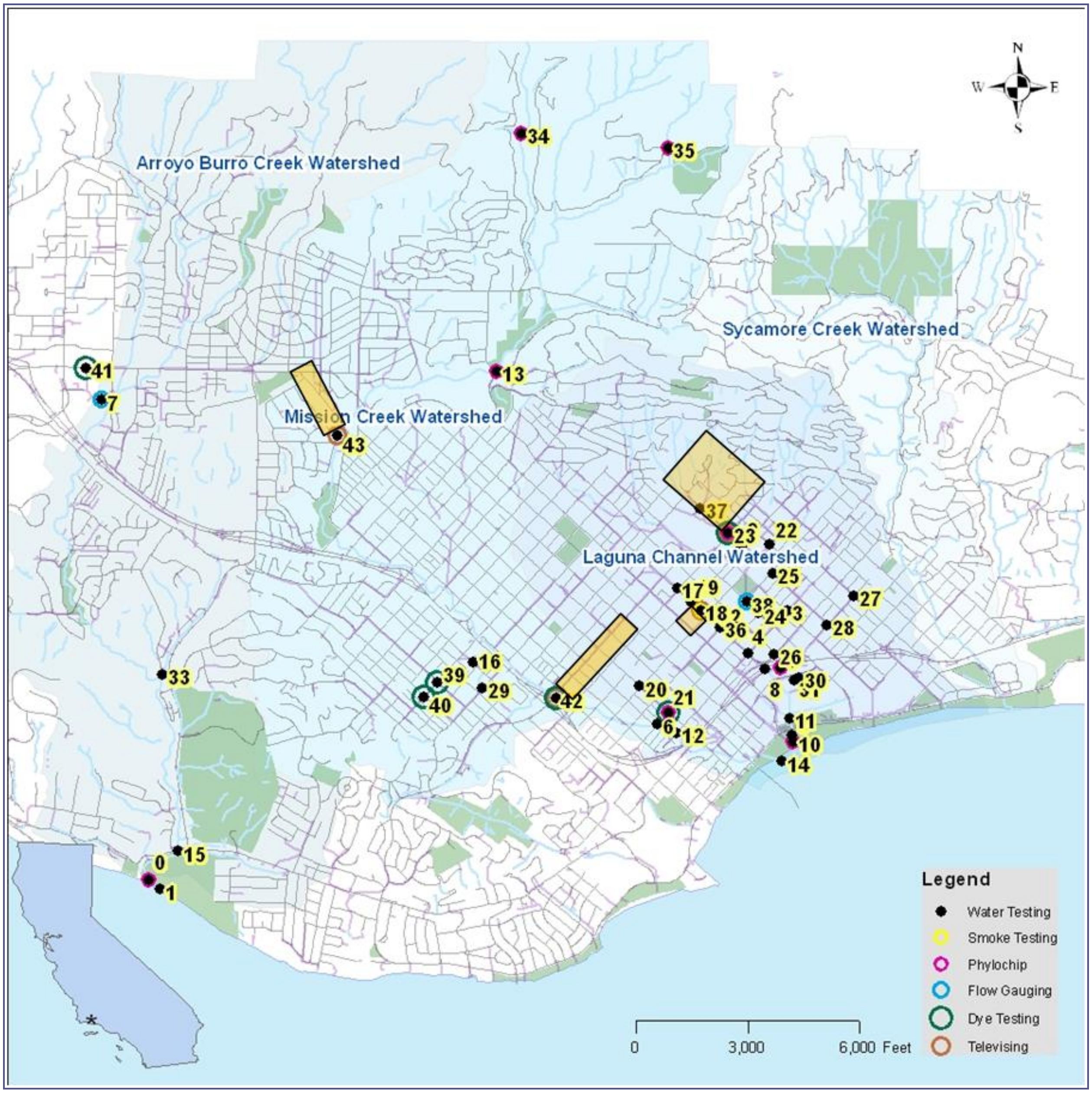



**FIGURE 7. LOCATIONS OF PROJECT ACTIVITIES. ORANGE SHADING REPRESENTS AREAS WHERE TELEVISING AND SMOKE TESTING WERE PERFORMED. FIGURE DOES NOT INCLUDE COMPREHENSIVE GIS AND CCTV WORK COMPLETED WITH GRANT AMENDMENT. SEE LOCATIONS SECTION BELOW FOR MORE DETAILED MAPS, LOCATION COORDINATES, AND REFERENCES TO WORK PERFORMED AT EACH SITE.**

Field research was performed throughout the City (Figure 7). The following report section, Locations of Monitoring Activities, includes more detailed maps (Figure 22, Figure 23, Figure 24) and coordinates (Table 5) of all project activities.

Methods for alternative sewage indicators were researched using the published literature, and selected methods were then recruited and tested for their usefulness in assessing sewage amounts in storm drains. Approaches for studying exfiltration in the field were researched, and a novel approach was developed that involved dispensing rhodamine wastewater tracer (RWT) dye into sanitary sewers and detecting a fluorescence signal continuously, in real time, in storm drain manholes using a field-deployable, battery-driven submersible optical probe with data logger (UCSB Final Report Chapter 4, Figure 8 below).


**FIGURE 8. RHODAMINE WASTEWATER TRACER (RWT) PROBE INSTALLED IN URBAN MANHOLE.**

The specificity of two similar, widely-used approaches for quantifying sewage contamination in water samples through quantitative polymerase chain reaction (qPCR) analysis of DNA markers in human waste was tested (UCSB Final Report, Chapter 4). This involved collecting fecal samples from various non-target (raccoon, gull, rat, dog, cat) hosts and target (human, septage, sewage) materials, then comparing the specificity of two popular qPCR-based approaches for quantifying human markers.

**EQUIPMENT ITEMS FOR FLOW MEASUREMENT IN STORM DRAINS AND AUTOMATED CONTINUOUS SAMPLING WERE RESEARCHED AND SELECTED, THEN DEPLOYED AT TWO LOCATIONS (SALSIPUEDES AND COTA, AND THE HOPE DIVERSION AT LA CUMBRE MALL) FOR 72 HOUR CAMPAIGNS TO BETTER UNDERSTAND TEMPORAL**

**VARIATION IN HUMAN WASTE CONTAMINATION AND IN STORM DRAIN FLOW (UCSB FINAL REPORT CHAPTER 4,**

Figure 9 below). Samples from these campaigns were analyzed for FIB and markers of human waste, plus nutrients and chemical markers of human waste (CUSB Chapter 7).


**FIGURE 9. FLOW GAUGE AND AUTOSAMPLER DEPLOYED IN URBAN STORM DRAIN.**

A high-density microarray of DNA probes, the PhyloChip was used to assess differences in fecal source bacterial communities for the non-target (as above) and human-associated (as above) fecal samples (UCSB Chapter 6). The fecal source bacterial community profiles by PhyloChip were then compared to water sample bacterial communities for samples collected in various sites of interest based on historical FIB and/or human DNA-marker contamination. This sub-study was intended to push the envelope on assessing the use of community-based fecal source tracking.

A GIS database was assembled with microbiological data—both historical from recent studies conducted by UCSB for the City and also from this study—displayed along with storm drains, sanitary sewers and streets with the latter three types of data already contained in the City GIS database as separate information sets (UCSB Final Report Chapter 10). The GIS assemblage of spatial, physical infrastructure, metadata of physical infrastructure (i.e. sanitary sewer age and material of construction, and depths and diameters of sanitary sewers and storm drains) and scientific information (microbiological and chemical analysis results) was used to generate several products for visualizing information and for planning remediation and research.

In addition to the work conducted with UCSB, the City investigated identified hot spots with closed circuit televising (CCTV), smoke testing, and traditional dye testing in storm drains. These tools have been employed traditionally in the investigation of sanitary sewer pipes; here they were used to search for leaks of sewage *into* storm drains.

Based on the results obtained, the City was suspicious that systematic leaking of sewer pipes to storm drains could be occurring throughout the City. The City proposed a modification of the grant agreement, without an increase in grant funds, to conduct televising of storm drains at every "intersection" identified where sewer lines were thought to lie above storm drains. In addition, dye testing was conducted in as many areas as possible to support televising results. Updated GIS maps were completed first, using additional infrastructure depth data found in City archives. Televising and dye studies were completed from January to July 2012.

### RESULTS

Of the two human-specific marker qPCR-based approaches for quantifying sewage contamination in field water samples, one approach—the approach already adopted and used previously for City-funded research by UCSB—was comparatively much more specific to human waste (UCSB Final Report Chapter 5). This approach (qPCR HF183, or HBM for human *Bacteroides* marker) was used to analyze field samples for other studies (exfiltration tracer study samples, and temporal variation samples) in this research.

Of the various potential chemical markers tested for use in tracing sewage in storm drains, three appeared useful: ammonium, phosphate, and anionic surfactants (methylene blue active substances, or MBAS). These markers appeared to be most useful when sewage contamination was greater than 10%; at concentrations less than approximately 10% (by volume of water samples), other background sources of these constituents confounded their relationship to sewage as a contamination source (UCSB Final Report Chapter 7). Other chemical markers previously employed and used here (caffeine and cotinine) were also found to be generally useful and more specific to human waste than ammonium, phosphate or surfactants. However, assays for both caffeine and cotinine are comparatively expensive and require laboratory expertise that is greater than assays for ammonium, phosphate and surfactants. Because ammonium and phosphate can be measured in the field easily, these approaches have additional advantages and were therefore folded into the source tracking protocol development.

The PhyloChip, used previously in other studies conducted by UCSB including prior research with the City in the Mission Creek area, was assessed in this study for its utility in discerning fecal sources from one another and from background microbial communities in field water samples. Based on all valid probe hybridization events, gull and raccoon microbial communities appeared distinct from all other microbial communities (UCSB Final Report Chapter 6). Water sample microbial communities by PhyloChip were indicative of sewage contamination in the Nopal/Canon Perdido area; cat and dog contamination was also present, which was concluded to arise with sewage due to how domestic pet feces may be disposed. PhyloChip analyses also indicated the presence of raccoon and possibly gull feces at Haley and Chapala. Other samples, where source-specific communities were not observed, may be contaminated by fecal indicator bacteria that are not related to fecal sources, i.e non-target bacteria that arise with FIB analysis.

The use of GIS for displaying and scrutinizing infrastructure data was beneficial in interpreting exfiltration results; GIS was also very useful for gaining overall perspectives of the spatial context of microbiological results (UCSB Final Report Chapter 10).  The methodology for building the GIS database was described, and examples of results (i.e. types of data displays) useful to planning research and remediation are demonstrated.

During the course of this Project, sewers leaking into storm drains were discovered and repaired in four locations (Figure 10): Nopal Street (Figure 11, Figure 12, and Figure 13), Carrillo Street (two sites; Figure 14, Figure 15, Figure 16, and Figure 17), and State Street (Hope Drain; ). An additional leak at Micheltorena Street to the Westside Storm Drain was found during the grant extension work (FIG). This site will be rehabilitated in the next year. Each of these sites was identified as problematic with water testing. Follow up with dye and/or camera testing, targeted with GIS maps and models, was used to confirm the exact location of sewage input to the storm drain.

In addition, one illicit connection where wash water from a plumbing contractor was discharged to the storm drain was discovered. An enforcement case was instigated and the washing drain has been diverted to sanitary sewer.

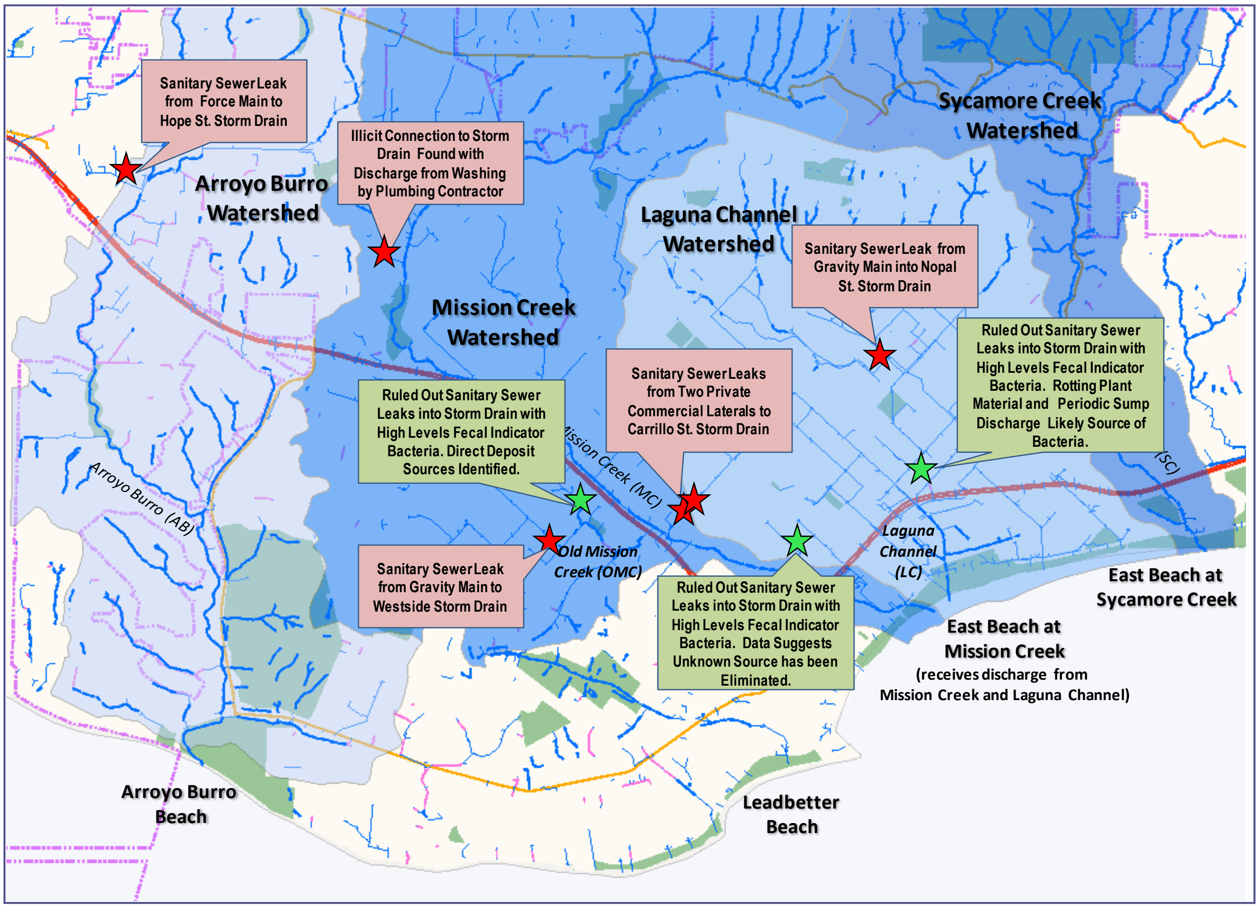



**FIGURE 10. LOCATIONS WHERE SANITARY SEWER LEAKS INTO STORM DRAINS WERE DISCOVERED DURING THIS PROJECT. AREAS IN WHICH SEWAGE LEAKS WERE SUSPECTED AT THE PROJECT ONSET, BUT WERE RULED OUT, ARE ALSO SHOWN.**

### Nopal Street Storm Drain

The Nopal Street Storm Drain became a target site for dye studies after water testing for human waste markers came back positive on several occasions (UCSB Final Report, Chapter 7). Based on GIS analysis, the nearby area contained several storm drains and sanitary sewer pipes that are in close proximity to each other (light and dark gray lines in Figure 11). Dye was inserted into several sanitary sewer manholes on three dates, and a probe was placed in a storm drain manhole downstream. Spikes of fluorescence were seen in the storm drain, confirming exfiltration of sewage from the sanitary sewer pipe and infiltration of the dye into the storm drain. The dye took at least 48 hours to reach the probe (Figure 11, UCSB Final Report Chapter 9, Sercu et al. in Appendix E).

Storm drain televising was chosen as the next tool to find the input. Televising in most of the drain on Nopal Street showed a clean pipe, with a trickle of visually clean water in the bottom. At many of the storm drain pipe joints, putatively clean groundwater infiltrated to the drain (Figure 12). However, while watching the televising take place real-time on the on-site monitor, water was seen trickling from a side storm drain that connected to a nearby catch basin (Figure 13). Quick field reconnaissance showed that the catch basin itself was dry. Using a remotely controlled scissor jack on the tractor's camera, the operator was able to raise the camera so that the monitor displayed video of the side drain itself.

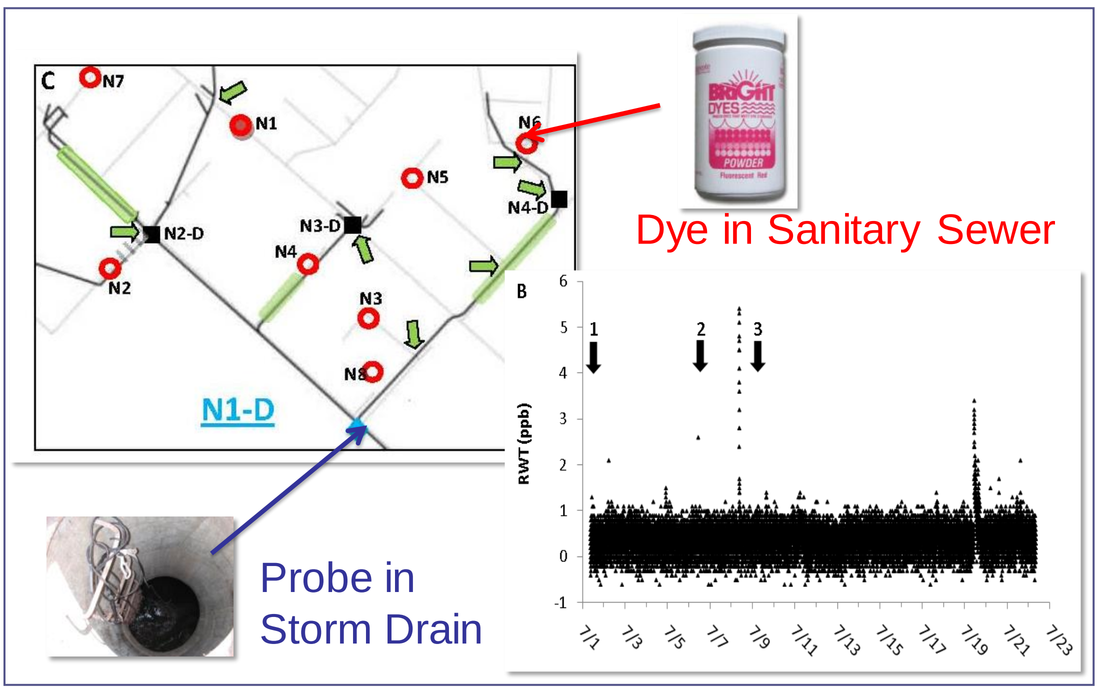



**FIGURE 11. DYE STUDY SHOWING SEWAGE INFILTRATION TO STORM DRAIN. IN MAP PANEL, GEEN ARROWS REPRESENT SHOW WHERE RHODAMINE WASTEWATER TRACER (RWT) WAS ADDED TO SANITARY SEWER PIPES. BLUE ARROW SHOWS WHERE RWT PROBE WAS DEPLOYD FOR TWO WEEKS. GRAPH SHOWS FLUORESCENCE READINGS EVERY TWO MINUTES, WITH PEAKS SHOWING ENTRY OF DYE INTO STORM DRAIN. BLACK ARROWS SHOW TIMING OF DYE PULSES INTO SEWER PIPES.**

Water flowing into the side drain was seen at a storm drain pipe joint; however, it did not have the seeping appearance of other joints. Water appeared to be coming from a source above the side drain, and the City was fairly certain that the source of sewage input had been located. The City's Wastewater Division arrived on scene, and after conducting additional televising of the sanitary sewer pipe and additional dye testing, the section of sanitary sewer pipe crossing above the storm drain was quickly replaced.

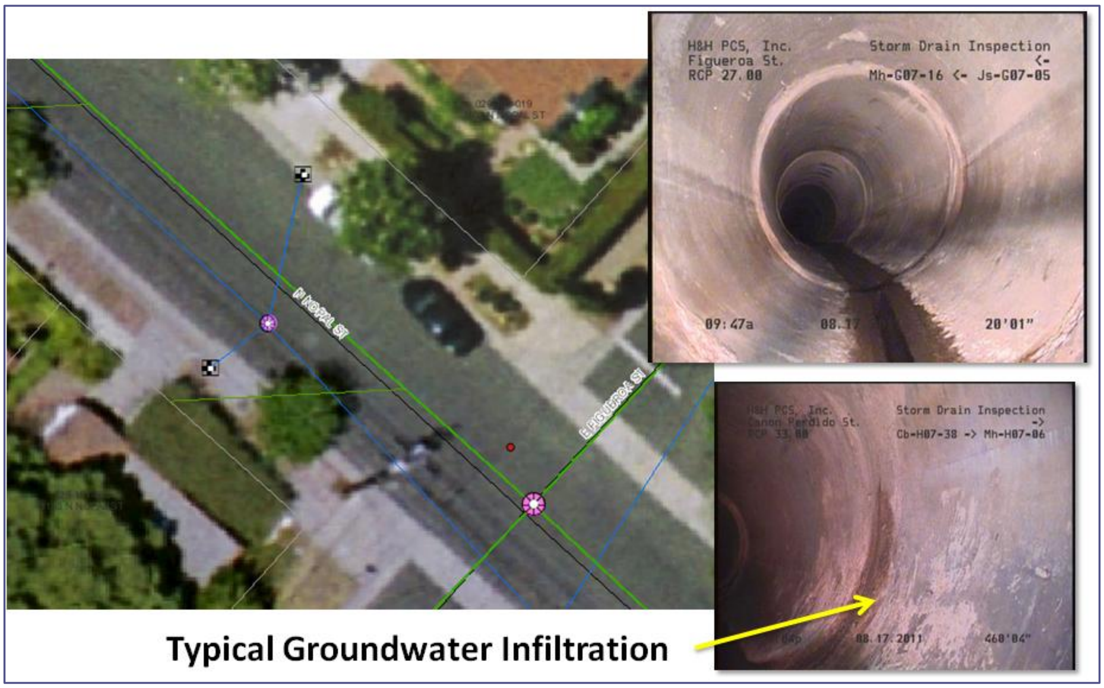



**FIGURE 12. CLEAN GROUNDWATER INFILTRATION IN NOPAL STREET STORM DRAIN. IN MAP ON LEFT, BLUE LINES REPRESENT STORM DRAIN PIPES AND GREEN LINES REPRESENT SANITARY SEWERS. PANEL ON UPPER RIGHT SHOWS FLOW OF VISUALLY CLEAN WATER IN STORM DRAIN. LOWER PANEL SHOWS TYPICAL VISUAL OF OSTENIBLY CLEAN GROUNDWATER SEEPING INTO STORM DRAIN AT PIPE JOINTS.**

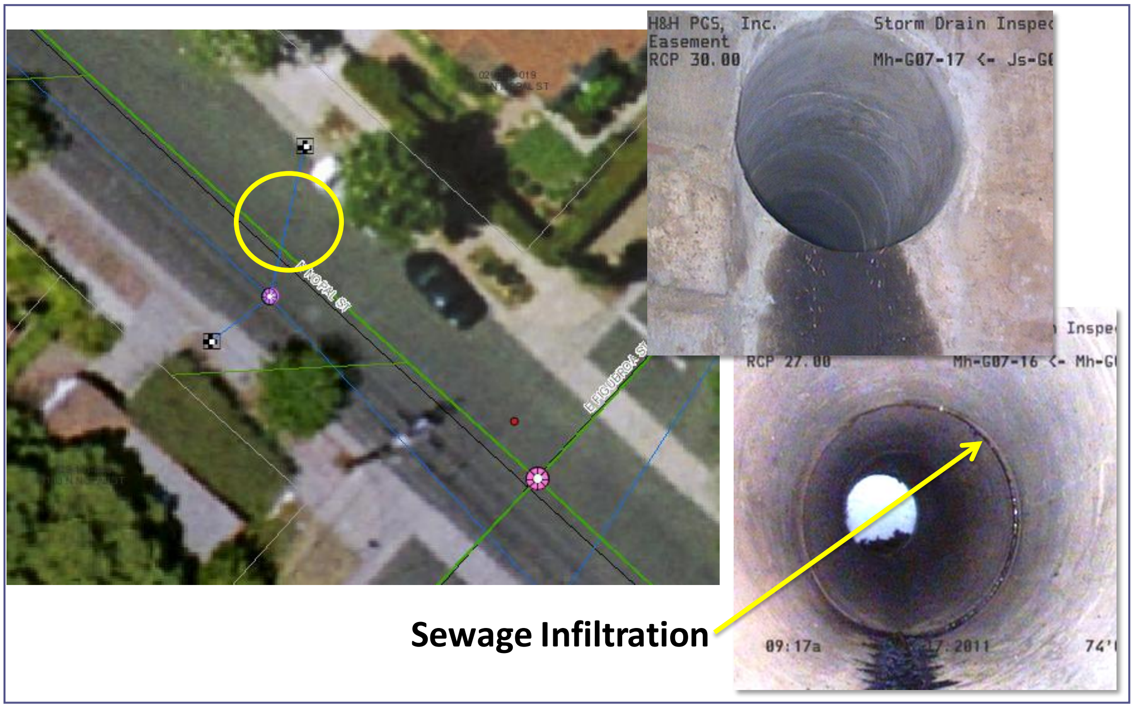



**FIGURE 13. SEWAGE INFILTRATION TO NOPAL STREET STORM DRAIN. IN MAP ON LEFT, BLUE LINES REPRESENT STORM DRAIN PIPES AND GREEN LINES REPRESENT SANITARY SEWERS. YELLOW CIRCLE SHOWS LOCATION WHERE A SANITARY SEWER PIPE CROSSES ABOVE A SIDE STORM DRAIN. PANEL ON UPPER RIGHT SHOWS FLOW INTO MAIN STORM DRAIN FROM SIDE DRAIN LEADING TO CATCH BASIN. VISUAL INSPECTION AT STREET LEVEL SHOWED THAT CATCH BASIN WAS DRY. LOWER PANEL SHOWS WATER LEAKING INTO SIDE DRAIN FROM ALMOST THE ENTIRE CIRCLE FORMED BY THE SIDE JOINT. THE LEAK WAS CONFIRMED TO BE UNTREATED SEWAGE.**

### CARRILLO STREET STORM DRAIN

The Carrillo Street Drain was found to have sewage from two leaking private laterals serving six businesses entering the storm drain prior to discharge into Mission Creek. The story was shared with the community in the Creeks Division E-news, which is shown here in Figure 14, Figure 15, and Figure 16). Once the leaks were confirmed by the City's Wastewater Division, the storm drain was sand bagged and all flow was vactored (suctioned) and taken to the sewage treatment plant. The property owners were notified immediately and repairs were made within 24 hours (Figure 17).

E



## Sewage Leak into Mission Creek Stopped

During a routine survey of Mission Creek at the concrete channel near Carrillo Street, Creeks Division staff noticed what appeared to be degraded toilet paper and brown sludge in water flowing from the storm drain that runs along West Carrillo Street.

Extremely high indicator bacteria levels, in addition to sporadic positive test results for human sewage markers during our DNA-based research efforts suggested that human waste was entering the storm drain. But where, and how?

Previous testing of water samples upstream in the storm drain network, along with televising part of the storm drain several years ago, did not reveal the source. Could it be occasional RV dumping, an intermittent sewage leak, or even people defecating near parking lot drains?

With a combination of persistence and teamwork, the Creeks Division and Wastewater Division identified two sources of untreated sewage entering the storm drain from compromised private sanitary sewer laterals.

*PHOTO: Dye testing revealed that private sewer laterals were leaking into the storm drain system, which flows from the Carrillo Drain into Mission Creek..*

The first source was comprised of untreated sewage from a commercial building, where a broken private lateral crossed through the top of the brick and mortar roof of the storm drain. The second, a much slower leak, came from a failing private lateral serving another commercial building.

Within 24 hours of confirming the sources of the leaks, contractors hired by the property owners had repaired the broken sewer laterals.

Click here for additional details on how this mystery was solved.

**Remember, if you see (or smell) pollution in the street, storm drain, or creek, call the Creeks Division's Enforcement Hotline at (805) 897-2688.**

Creek Week
Santa Barbara
Carpinteria – Goleta

### Creek Week Planning has Begun!

The 12th Annual Creek Week is scheduled for September 17 - 25, 2011.

The week-long celebration features a wide variety of events hosted by various community organizations.

For more information, please visit www.sbcreekweek.com.

### Job Opportunity for Environmental Educator

If you enjoy working with kids and are passionate about the environment, this may be the job for you!

Our friends at Art From Scrap (who provide much of our youth watershed education) are currently hiring for a new Environmental Educator to begin August 15th.

Click here for details!

Like the Creeks Division on Facebook!

**FIGURE 14. SEWAGE LEAK INTO CARRILLO STREET STORM DRAIN, PART 1.**

City of Santa Barbara - June2011_Sewer_Lateral

- Water Conservation
- Contacts
- Rates, Forms & Documents
- Water Supply
- Water System
- Wastewater System
- Frequently Asked Questions
- Water Resources Links
- Youth Programs
- Youth Sports
- Jesusita & Tea Fire Rebuild Information
- 1900 Lasuen Road (El Encanto Hotel)
- 200 Block of Chapala Street (Chapala Street Bridge Replacement Project)
- 210 West Carrillo Street
- 210 and 216 Meigs Road and 290 Lighthouse Road
- 226 and 232 Eucalyptus Hill Drive
- 316-324 State Street and 323 Anacapa Street
- 3714 - 3744 State Street
- 3757 - 3771 State Street
- 400 Block of South Fairview Avenue
- 457 North Hope Avenue
- 4151 Foothill Road, 681 Cieneguitas Road, and 675 Cieneguitas Road
- 500 James Fowler Road (Goleta Slough)
- 535 East Montecito Street
- 540 West Pueblo Street (Cancer Center of Santa Barbara)
- 6401 Hollister Avenue
- 803 N. Milpas Street
- 900 - 1100 Las Positas Road (Veronica Meadows)
- 900 Calle de Los Amigos (Valle Verde)
- 915 East Anapamu Street
- 920 Summit Road
- 930 Miramonte Drive
- Cottage Hospital
- De la Guerra Plaza
- Douglas Family Preserve Management Plan
- Inclusionary Housing Ordinance Amendment
- Paseo de la Playa - 101 Garden St, 222 Santa Barbara St and 301 E. Yanonali St
- Pedestrian Master Plan
- Santa Barbara Cottage Hospital Foundation Workforce Housing Project
- Santa Barbara Zoological Gardens

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**Continued from the July 2011 Creeks Division E-News...**

During a routine survey of Mission Creek at the concrete channel near Carrillo Street in June 2011, Creeks Division staff noticed what appeared to be degraded toilet paper and brown sludge in water flowing from the Carrillo Drain. It was later learned that fire hydrant flushing in the drainage likely forced this material out of the drain, making it more visible in the creek channel.

Sampling conducted that afternoon and several times over the next week returned high values of ammonia, an indicator of urine, as well as high levels of fecal indicator bacteria.

Staff suspected a broken sewer lateral could be the source of the problem, so the Creeks Division hired a contractor to survey the interior of the storm drain using a state-of-the-art robotic camera (see photo above). Our suspicions were confirmed when two locations were found where water was dripping into the storm drain (see screen shot below).

http://www.santabarbaraca.gov/Resident/Community/Creeks/June2011_Sewer_Lateral (1 of 3)7/16/2012 10:57:59 PM

**FIGURE 15. SEWAGE LEAK INTO CARRILLO STREET STORM DRAIN, PART 2.**

City of Santa Barbara - June2011_Sewer_Lateral

Sycamore Creek and Punta Gorda Street Bridge Replacement Project
Wildland Fire Plan Environmental Impact Report


The next day, Creeks Division and Wastewater Division staff flushed fluorescent green dye in the toilets of nearby businesses (USGS confirms that this dye can enter creeks without causing toxicity problems). After a few flushes, the bright green stream was observed flowing out of the storm drain into Mission Creek (see photo below).

A similar procedure was used to identify the second leak, and private property owners repaired the leaking sewer laterals within 24 hours of confirming the sources (see photo of one repair below). Following the repairs, the Creeks Division has observed no water at all coming from the Carrillo Drain into Mission Creek.

http://www.santabarbaraca.gov/Resident/Community/Creeks/June2011_Sewer_Lateral (2 of 3)7/16/2012 10:57:59 PM

**FIGURE 16. SEWAGE LEAK INTO CARRILLO STREET STORM DRAIN, PART 3.**

**FIGURE 17. REPAIR OF SEWAGE LEAK INTO CARRILLO STREET STORM DRAIN.**

### Hope Avenue Storm Drain

Early testing (several years prior to the current Project) at the discharge of the Hope Avenue Storm Drain into Arroyo Burro showed high levels of fecal indicator bacteria. Based on the high indicator bacteria results, a Proposition 40 Clean Beaches Initiative-funded low-flow diversion was installed that shunts dry weather flows in the storm drain to the nearby sanitary sewer pipe for treatment at El Estero Wastewater Treatment Plant (Figure 18). During project design, in 2005, testing by Dr. Holden confirmed the presence of human-waste markers at this location. The City and Dr. Holden also tested numerous samples in the storm drain network leading to this location. Results were difficult to interpret and did not lead to the identification of a point input to the Hope Avenue Storm Drain. During the Canine Scent Tracking Project (Appendix D), positive canine responses were found in one branch of the storm drain network, and a sewage input was strongly suspected and narrowed to a reach of pipe that crossed a busy arterial, State Street.

Using tools being tested for the current Project, the City's Wastewater Division brought in a closed circuit televising rig within the hour, and the storm drain was surveyed for water input. During the first 30 minutes of filming, no visible inputs were detected. Confounding the investigation was an illicit hot tub discharge to the catch basin (via the street gutter) at the terminal end of the storm drain. The warm flow upstream of the suspected input location made it difficult to convince ourselves that flow downstream contained sewage; however, the smell in the storm drain at this location smelled very strong. Experienced camera operators thought that a sag in storm drain may cause rotting organic material to putrefy and result in an anaerobic odor. Fortunately, the camera was left filming while field reconnaissance was taking place. Staff watched the monitor even though the camera was still, and eventually saw periodic dripping and trickling into the storm drain. The flow was synchronous with sounds heard from the catch basin. Additional camera work showed the flow in more detail. Ammonia testing came back with high results (data not shown) and the Wastewater Division planned for repair of the site within 24 hours (Figure 19). Because the drain was being diverted to sanitary sewer, no vactoring was necessary. The intermittent flow was the result of a force main sanitary sewer line crossing perpendicular to and above the storm drain. The force main was under pressure periodically and pushed untreated sewage through a crack in the cement casing that held the storm drain and sewer pipe. Prior to the repair being completed, UCSB tested the RWT probe method as a proof of concept (UCSB Final Report Chapter 9, Sercu et al. 2011). Several months after the repair, the Hope Avenue Storm Drain was used as the site for flow monitoring and automated sampling. The sampling showed that there were no positive markers for human waste in the drain (UCSB Final Report Chapter 8).

The City continues to operate the diversion because of the commitment made in the grant agreement for the diversion project. Interestingly, fecal indicator bacteria levels have not decreased significantly at the drain outflow since the leak was discovered and repaired. Pathogens have certainly been eliminated from the creek and coastal ocean.

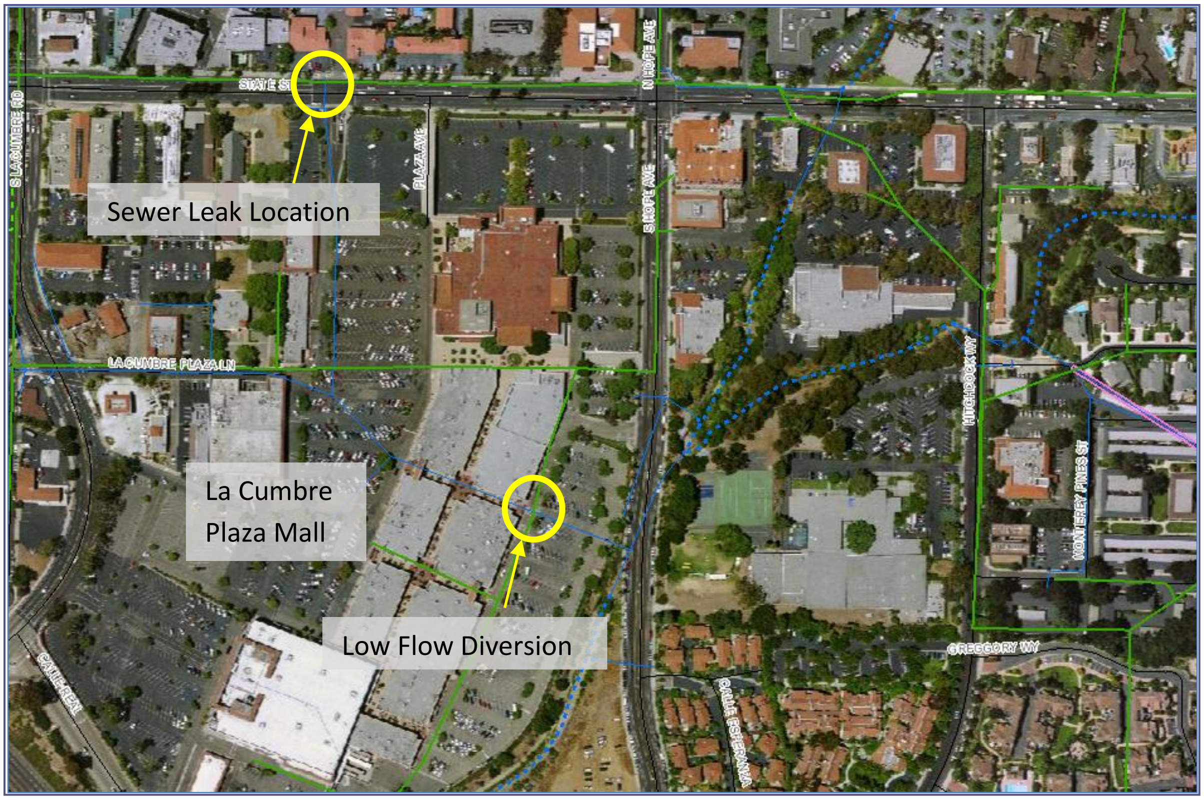


**FIGURE 18. LOCATION OF THE HOPE AVENUE STORM DRAIN SEWAGE LEAK. GREEN REPRESENTS SANITARY SEWER PIPES, SOLID BLUE LINES REPRESENT STORM DRAINS, AND DASHED BLUE LINES REPRESENT CREEKS.**

**FIGURE 19. REPAIR OF SEWAGE LEAK INTO HOPE AVENUE STORM DRAIN.**

### RULING OUT SEWAGE LEAKS

In addition to the discovery and elimination of sewage leaks during the Project, the methods have also been used to rule out sewage inputs to drains with traditionally high indicator bacteria levels.

### HALEY STREET STORM DRAIN

Based on previously obtained results showing several years of consistently positive results for human waste markers, the Haley Street Storm Drain was chosen as a target site for this project. Like the Hope Avenue Storm Drain, the Haley Street Storm Drain is also diverted to the sanitary sewer during dry weather, with funding from the Proposition 40 Clean Beaches Initiative Grant program. During this Project, samples were collected from several locations feeding the Haley Street Storm Drain (Figure 23) and they did not show positive results for human waste markers (UCSB Final Report Chapter 8). Dye studies were also conducted in the area, to serve as a negative control due to the lack of close proximity between storm drains and sewer pipes. Dye results are shown in Figure 20. Therefore, both dye and microbiological data suggest no or low sewage contamination due to exfiltration from sanitary sewers in this area. Additional data and discussion are provided in the UCSB Final Report, Chapter 9. In light of the GIS-based display of sanitary sewer versus storm drain orientations (depths, and parallel or crossing), this result from the exfiltration study is logical: sanitary sewers and storm drains are quite spatially distant, at least vertically, in the region (Chapala from Canon Perdido to Haley Street) studied. Thus, this latter area served as a good negative control for dye tracing exfiltration from sanitary sewers to storm drains.

Based on results in this Project, the drain now appears “clean.” It is not known if there was an infrastructure (including repair of private laterals) or behavioral change at this location leading to the improved water quality. Because behavioral changes could occur again, and due to the commitment made in the grant agreement for the diversion, the low-flow diversion of Haley Drain will continue to operate during dry weather.

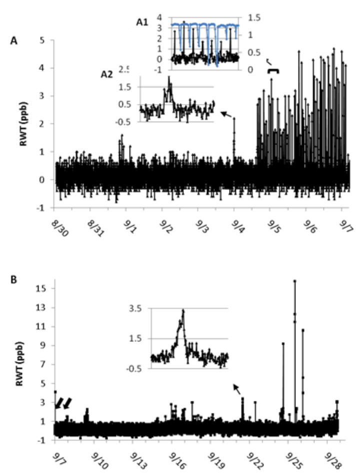


**FIGURE 20. RHODAMINE CONCETRATIONS AT HALEY DRAIN. A. BACKGROUND, PRIOR TO RELEASE OF DYE. INSET A1 SHOWS DETAIL WITH CONDUCTIVITY IN BLUE LINES ON RIGHT Y-AXIS. INSET A2 SHOWS DETAIL OF RWT**

**PEAK. B. RWT CONCENTRATIONS AFTER DOSING ONE RWT PULSE IN EACH SANITARY SEWER MANHOLE (DOSING TIMES INDICATED BY ARROWS).**

### San Pascual Drain

The San Pascual Street Storm Drain discharges to Old Mission Creek, a tributary of Mission Creek. Based on early sampling results of extremely high indicator bacteria in storm drain samples from the drain (Site 16 in Figure 22). One previous test for human waste markers came back positive as well. Based on these results, and the fact that the Old Mission Creek flows through Bohnett Park, where children play in the creek, this drain was proposed for a low-flow diversion to sanitary sewer during the first Proposition 84 Clean Beaches Initiative conceptual proposal opening. During the current Project, the entire drain was televised and field reconnaissance was conducted. The storm drain was shown to contain extensive infiltration with clean groundwater, as it likely passes through the old channel and deposits of Old Mission Creek, which was rerouted to the other side of the 101 freeway early in the 20$^{th}$ century. Nearing the drain outlet, stagnant and discolored water backed up the storm drain. A weir downstream of the outlet causes the backup and likely high indicator bacteria levels. In addition, high-density residences nearby were likely sources of urine-filled bottles and diapers being tossed into the stagnant water. This direct input is the likely source of occasional positive results for human waste markers. The City added the site to the weekly list of sites that is cleaned by a contractor.

### Supplemental Work

Based on the observation that every sewage leak detected in the Project was located where a sewer line (gravity main, force main, or private lateral) crossed perpendicular to, and above a storm drain, the City requested a no-cost grant amendment to conduct systematic televising of every identified “intersection” in the City. Results of this effort are provided in Appendix C.

In summary:

- Systematic dye testing found at least one location where sewage is infiltrating to the storm drain (Figure 21). Dye testing is an affordable, relatively simple method to cover large areas of suspected sewage leaks.
- The systematic televising approach without relying on previous water testing results found fewer leaking areas than expected.
- Televising work did not identify new sewer leaks. Many storm drains were shown to have extensive infiltration, but it was difficult to determine if the infiltration was occurring from clean groundwater or was, in fact, contaminated. No clear roof leaks were detected.
- In several locations, sanitary sewer pipes crossed directly through storm drains, and in most of these cases, water appeared to be leaking from the sewer pipes. However, water testing for fecal indicator bacteria and ammonia did not confirm sewage leaks.
- Televising identified several illicit connections to the storm drain system, but none were found to originate from toilet fixtures.

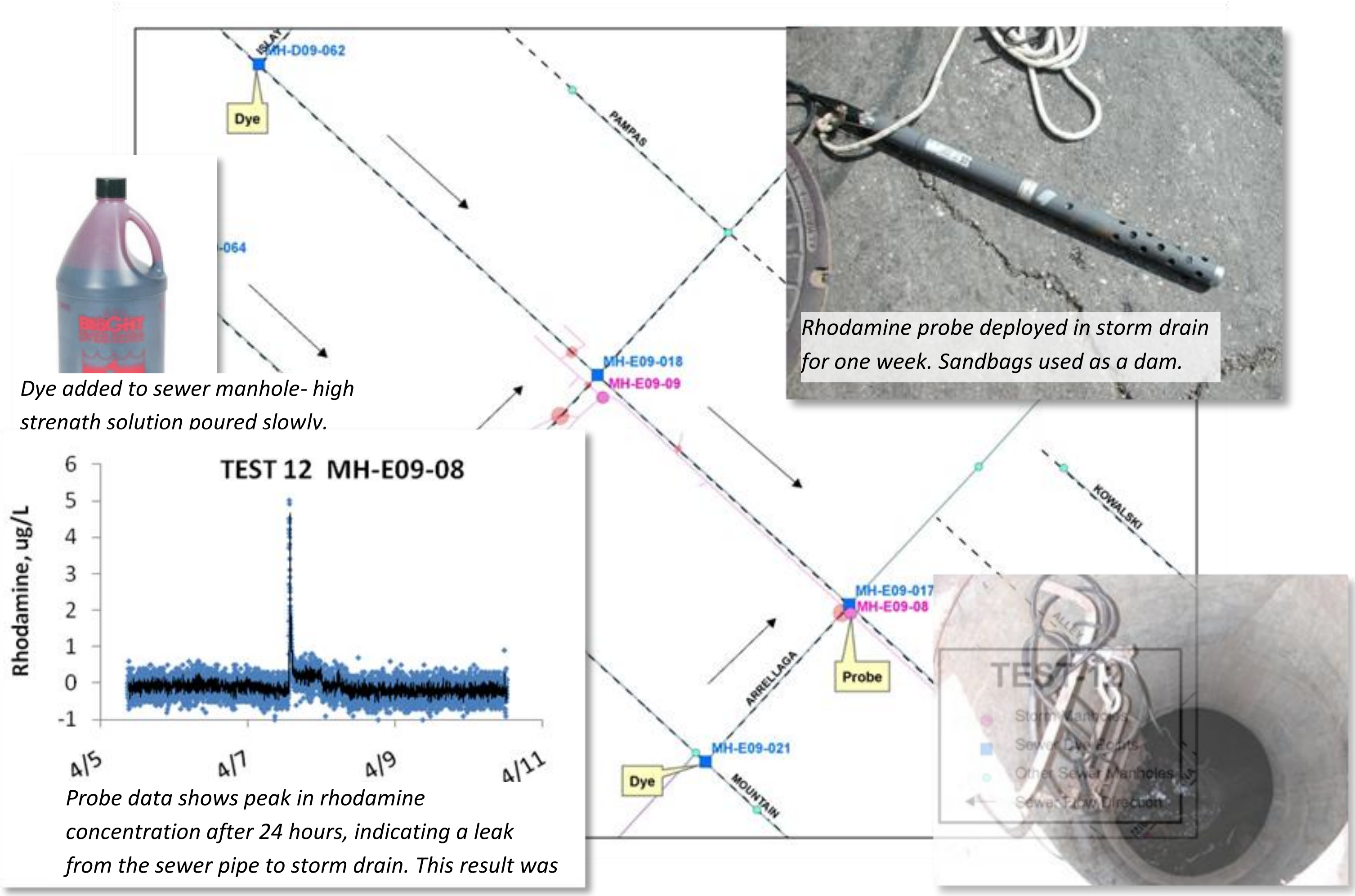


**FIGURE 21. INVESTIGATION OF DIFFUSE FLOW BETWEEN SANITARY SEWER PIPE AND STORM DRAIN.**

## Locations of Monitoring Activities

All field activities in the research project described here are considered "Monitoring Activities." There were no Management Practices included in the grant agreement. Therefore, this section describes locations of all Project and Monitoring Activities completed.

Project sites are numbered in Figure 7, Figure 22, Figure 23, and Figure 24. Coordinates of each location are provided in Table 5. Activities associated with each site are color coded in the figures and notes in Table 5. Table 5 also provides references to report sections for each activity category.

**TABLE 5. PROJECT LOCATIONS AND ACTIVITIES**

| Site No. (Figure 7, Figure 22, Figure 23, Figure 24) | Longitude | Latitude | City of SB Station ID | UCSB ID | Water Sampling (UCSB Ch. 7) | Phylo-chip (UCSB Ch. 6) | Flow (UCSB Ch. 8) | Dye (UCSB Ch. 9) | CCTV (App A) | Smoke (App. A) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | -119.742627 | 34.402739 | AB Est Mou | A2 | x | x | | | | |
| 1 | -119.741624 | 34.402011 | AB Surf | A1 | x | | | | | |
| 2 | -119.690388 | 34.428051 | CB-H07-30 | L17 | x | | | | | |
| 3 | -119.686271 | 34.42336 | CB-H08-29 | L13 | x | | | | | |
| 4 | -119.689674 | 34.420183 | CB-H09-45 | L6 | x | | | | | |
| 5 | -119.686732 | 34.419176 | DI-H09-08 | L11 | x | x | | | | |
| 6 | -119.697638 | 34.414827 | Haley MC | M5 | x | | | | | |
| 7 | -119.747534 | 34.438021 | Hope Div | A5 | x | | x | | | |
| 8 | -119.688181 | 34.419017 | LC Hwy101 | L5 | x | | | | | |
| 9 | -119.685595 | 34.414182 | LC Pump | L3 | x | | | | | |
| 10 | -119.685524 | 34.413717 | LC Pumplag | L2 | x | x | | | | |
| 11 | -119.685829 | 34.415455 | LC Railroa | L4 | x | | | | | |
| 12 | -119.695902 | 34.414245 | MC Gutierr | M1 | x | | | | | |
| 13 | -119.712424 | 34.440655 | MC Rocky N | M2 | x | x | | | | |
| 14 | -119.686469 | 34.412233 | LC Surf | L1 | x | | | | | |
| 15 | -119.740039 | 34.404848 | Mesa lower | A3 | x | | | | | |
| 16 | -119.714098 | 34.419146 | MH-E09-01 | M9 | x | | | | | |
| 17 | -119.696081 | 34.424871 | MH-G08-04 | L10 | x | | | | | |
| 18 | -119.693931 | 34.42328 | MH-G08-06 | L8 | x | | | | x | x |
| 19 | -119.694817 | 34.423944 | MH-G08-10 | L9 | x | | | | | |
| 20 | -119.699256 | 34.4176 | MH-G09-12 | M7 | x | | | | | |
| 21 | -119.696703 | 34.415717 | MH-G10-07 | M6 | x | x | | x | | |
| 22 | -119.687887 | 34.428267 | MH-H07-03 | L16 | x | | | | | |
| 23 | -119.691584 | 34.428975 | MH-H07-13 | N4 | x | x | | x | x | |

| Site No. (Figure 7, Figure 22, Figure 23, Figure 24) | Longitude | Latitude | City of SB Station ID | UCSB ID | Water Sampling (UCSB Ch. 7) | Phylo-chip (UCSB Ch. 6) | Flow (UCSB Ch. 8) | Dye (UCSB Ch. 9) | CCTV (App A) | Smoke (App. A) |
|---|---|---|---|---|---|---|---|---|---|---|
| **24** | -119.688778 | 34.423129 | MH-H08-11 | L14 | x | | | | | |
| **25** | -119.687611 | 34.426056 | MH-H08-16 | N3 | x | | | | | |
| **26** | -119.687331 | 34.420126 | MH-H09-06 | L12 | x | | | | | |
| **27** | -119.680352 | 34.424519 | MH-J08-06 | N2 | x | | | | | |
| **28** | -119.682677 | 34.422347 | MH-J08-08 | N1 | x | | | | | |
| **29** | -119.713268 | 34.417256 | WSD | M8 | x | | | | | |
| **30** | -119.685077 | 34.418453 | Reclaimed | REC | x | | | | | |
| **31** | -119.68555 | 34.418202 | SewageIn | SEW | x | | | | | |
| **32** | -119.692804 | 34.423028 | CorpYardWell | GW | x | | | | | |
| **33** | -119.741712 | 34.417846 | LPCusLPC | A4 | x | | | | | |
| **34** | -119.710607 | 34.458214 | MCBotanic | M3 | x | x | | | | |
| **35** | -119.697536 | 34.457337 | Rattlesnake | M4 | x | x | | | | |
| **36** | -119.692239 | 34.422065 | MH-H08-14 | L7 | x | | | | | |
| **37** | -119.694129 | 34.430828 | MH-G07-16 | N5 | x | | | | | |
| **38** | -119.689864 | 34.423942 | MH-H08-10 | L15 | x | | x | | | |
| **39** | -119.71727 | 34.417647 | MH-E09-03 | MH2 | x | | | x | | |
| **40** | -119.718456 | 34.41657 | MH-E09-06 | MH | x | | | x | | |
| **41** | -119.748994 | 34.440352 | DI-B05-11 | A6 | x | | | x | | |
| **42** | -119.7067 | 34.416638 | CarrilloMC | | x | | | x | x | |
| **43** | -119.7265 | 34.43568 | SerenaMC | | x | | | | x | |

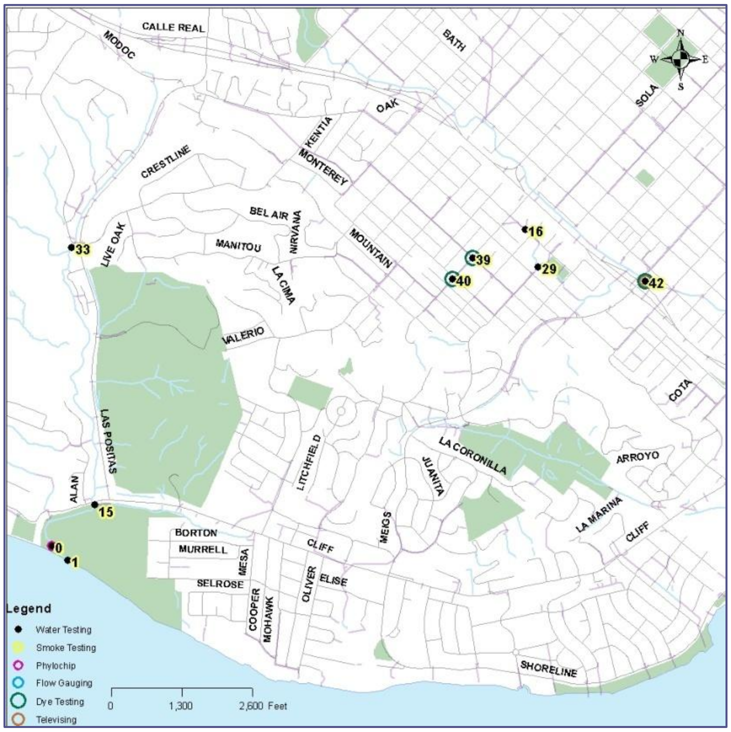


**FIGURE 22. PROJECT LOCATIONS AND ACTIVITIES IN LOWER ARROYO BURRO WATERSHED AND THE WESTSIDE NEIGHBORHOOD OF SANTA BARBARA.**

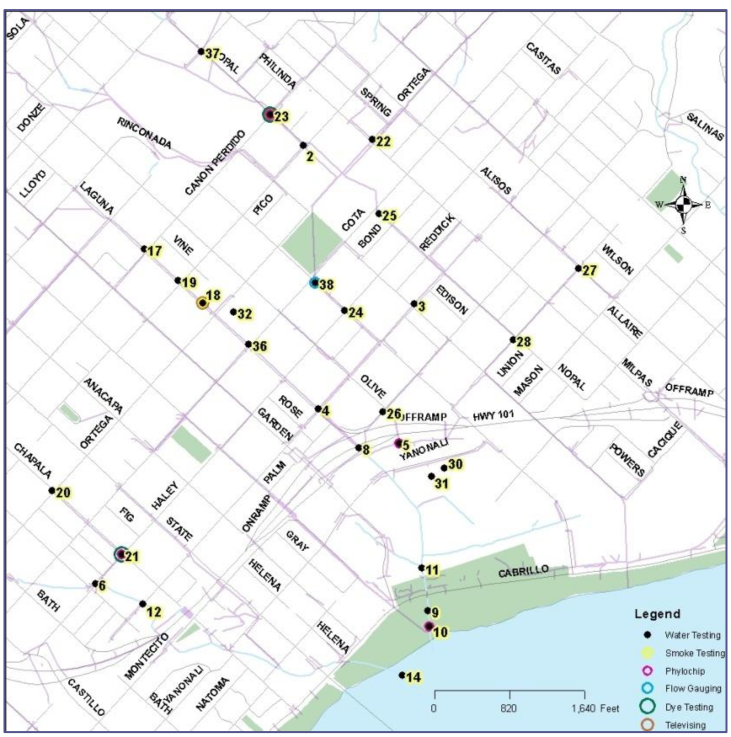


**FIGURE 23. PROJECT LOCATIONS AND ACTIVITIES IN THE HALEY DRAIN AREA AND LAGUNA WATERSHED IN SANTA BARBARA.**

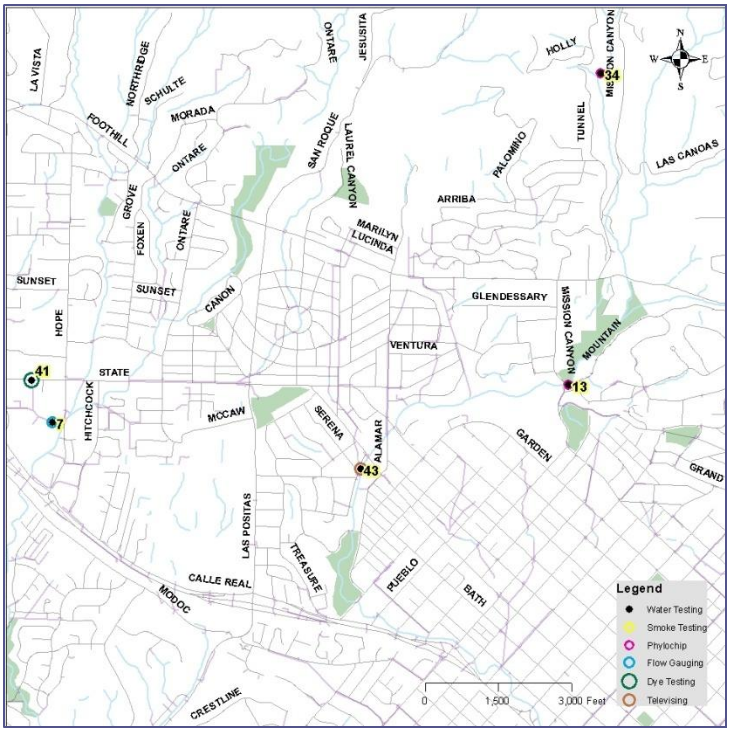


**FIGURE 24. PROJECT LOCATIONS AND ACTIVITIES IN THE UPPER STATE STREET NEIGHBORHOOD AND THE UPPER MISSION CREEK WATERSHED IN SANTA BARBARA.**

Additional televising work and dye studies were carried out during the Grant Extension. The activities took place throughout the City and are detailed in Appendix C. In addition, during the Grant Freeze period, work was conducted throughout the City using Canine Scent Tracking. The sites for this work are detailed in Appendix D.

## PROJECT SCOPE/ACTIVITIES COMPLETED

The project was completed according to the scope described in the grant agreement, with activities completed as follows. Discussion of each item is provided in *italic text*. References are provided to the supporting reports, photos, and other supporting material. If an item was not completed entirely, the reasons are discussed with the item.

1. Purchase, install and test field and lab equipment, including: toolkits for investigating connections between sanitary sewers and storm drains (flow meter(s), sensors, and autosamplers, field Geographic Information System (GIS/GPS, and/or smoke, televising, and dye testing equipment), and quantitative polymerase chain reaction (PCR) instrument (Holden Lab-University of California Santa Barbara [UCSB]). *Completed.*

1.1 Submit photo documentation of installation and testing of source tracking equipment to Grant Manager. *This item was completed and submitted to the Grant Manager on 12/8/2010.*

2. Develop detailed sampling plans for field investigation.

2.1 Prepare detailed sampling plans for each sampling season, as defined in Health & Safety Code section 115880 (AB411 Season) of the contract period by March of each year and September 2011. Conduct meetings with City staff and Dr. Holden's laboratory group to finalize sampling plans. *Completed. The sampling plan required in September 2011 was added during the grant amendment, with the additional work described in Item 3.3.*

2.2 Submit final sampling plans to the Grant Manager. *This item was completed.*

3. Conduct field sampling over two (2) AB411 Seasons and November 2011-March 2012.

3.1 In the summer of 2010, investigate diffuse flow as a source storm drain contamination. Submit photo documentation of field work to Grant Manager. *Submitted to Grant Manager on 7/28/2010 and 5/24/2012.*

3.1.1 Deploy automatic in-channel flow monitors and autosamplers. Measure flow, pH, turbidity, temperature, and conductivity continuously over the course of twenty-four (24) hours, and recorded in five (5)-minute intervals using Doppler technology based on velocity and area of flow. Repeat experiment on three (3) or four (4) days (non-consecutive) during the AB411 Season. *It was decided that additional sensors for conductivity and temperature would be sufficient for recognizing pulses of storm drain flow, and that additional sensors would not be justifiable economically. See UCSB Report and the Guide for Coastal Managers for additional information.*

3.1.2 Use a dual tracer technique to look for transport of Rhodamine WT and NaCI between sewer pipe and storm drains. *This item was completed by using conductivity as a proxy for NaCl.*

3.1.3 Program toolkits to collect samples every six (6) hours. Program storm drain toolkits to collect additional samples when flow is recorded that is substantially higher than the background value. *Completed.*

3.1.4 Conduct additional sampling upstream and downstream where additional flow gauges already exist at Mission Creek in Rocky Nook Park, and Mission Creek at Montecito Street. *It was determined that flow differencing would not work due to errors in flow measurements at low flow. Flow differencing relies on accurate measurements of flow in at least two locations. Through this project and literature reviews, it was determined that measurements of low flows in creeks can include errors of up to 200%. Water samples were collected in creeks for wastewater chemicals, as described in the UCSB Report Chapter 8.*

3.1.5 Maintain flow gauges, sondes, sensors, and data loggers in the manholes to record flow variability twenty-four (24) hours a day for up to two (2) weeks at each manhole. Move toolkits to additional manholes and storm drain networks based on results.. *Completed. Described in UCSB Final Report.*

3.1.6 During sampling periods, perform reconnaissance in the surrounding neighborhood to observe direct deposit of waste material into drop inlets in the drainage area. *Completed.*

*The following provides two examples of the importance of field reconnaissance:*

- *Near the Carrillo St. Storm Drain, sampling suggested that in the upstream reach (two blocks between State St. and Chapala St., ammonia concentrations were especially high. In addition, wastewater indicators at the outfall came back positive for caffeine and cotinine (a nicotine metabolite), but negative for the human feces markers Bacterioides and Mnif. Camera work eventually found a sewer lateral discharging to the storm drain, as described above. In addition, field reconnaissance led to the discovery of a fence area near a long-distance bus station that was used frequently for urination, leading the extremely high ammonia values. The malodorous area was cleaned with disinfectant that may also have contained ammonia. The bus station owner was contacted and the situation has been improved.*
- *Near the Nopal St. Storm Drain, a transient woman became very interested in sampling that was being conducted. She readily discussed the use of curb inlets for urination, potentially confounding sampling results.*

3.1.7 Based on preliminary results, investigate potential sources upstream of sampling reach. *Completed.*

3.2 In the summer of 2010, sampling locations and field work will depend on results from 2009. For example, if results from 2009 lead to identification of sources in Haley Drain area, repeat effort at additional key storm drain networks, such as the Carrillo or Victoria drains. In the Fall 2011- Winter 2012, use CCTV to inspect and record storm drains at 127 overlap points where sewer mains are shallower than storm drain pipes, starting with 91 locations where the sanitary sewer pipes are confirmed to be vitrified clay pipes installed 70-122 years ago. Proceed with video inspection at least one block in the upstream and downstream direction, checking for signs of leaking private sanitary sewer laterals (private laterals are not accurately recorded on City's GIS). If dampness or leaks are found, use dye testing and CCTV video inspection of sanitary sewer lines to inspect for roots or cracks. Produce log of inspections and results in order to determine the proportion of aging-infrastructure intersections that are leaking, thereby creating cross contamination from the sanitary sewer to storm drain. Submit copies of field notebooks to Grant Manager. *Completed, and copies of field notebooks submitted May 24, 2012.*

*Carrillo Drain wasinvestigated as described in the Guide for Coastal Managers and in the Outreach Section, below. Haley Drain was investigated as described above.*

*In Winter 2012, GIS models and infrastructure databases were improved and the identification of targeted intersections was repeated. CCTV was used to investigate all identified intersectionstwere accessible to camera crews. Details of the effort and results are presented in Appendix C.*

*In addition, dye studies were carried at the majority of targeted intersections, if flow was seen in the storm drain and if suitable dye and probe locations were identified. These efforts are described in Appendix C.*

3.3 Beginning in the Fall 2011, use Closed Circuit Television (CCTV) to inspect and record stormdrains at one hundred twenty seven (127) overlap points where sewer mains are shallower than storm drain pipes, starting with ninety-one (91) locations where the sanitary swer pipes are confirmed to be vitrified clay pipes installed seventy to one hundred twenty-two (70 – 122) years ago. Focus shall be on areas not already identified in the City's Sanitary Sewer Management Plan as requiring repair, rehabilitation or replacement due to known leakage. Proceed with video inspection at least one (1) block in the upstream and downstream direction, checking for signs of leaking private sanitary sewer laterals (private laterals are not accurately recorded on City's GIS). If dampness or leaks are found, use dye testing and CCTV video inspection of sanitary sewer lines to inspect for roots or cracks. Produce log of inspections and results in order to determine the proportion of aging-infrastructure intersections that are leaking, thereby creating cross contamination from the sanitary sewer to storm drain. Submit copies of field notebooks to the Grant Manager. *This item was completed.*

3.4 Throughout field-sampling seasons, maintain awareness of sample status and adapt sampling to respond to sustained periods of contamination. *This item was completed*.

*The City of Santa Barbara uses data collected by the County of Santa Barbara at AB411 beaches to determine when sustained contamination may occur, as mandated by state law..Based on this requirement and frequent beach warnings at Arroyo Burro in summer 2010, data analysis and sample collection was used to investigate potential sewage contamination. No obvious source of sewage contamination was found that would lead to sustained beach warnings during this period.*

4. Laboratory Analysis.

4.1 Process samples for indicator bacteria (using IDEXX methods) and Bacteroides (using quantitative PCR methods) according to QAPP. Submit laboratory log books of in-house analyses to Grant Manager. *Completed and submitted on 7/28/2010 and 8/4/2011. Details about sample results are provided in the UCSB Final Report.*

4.2 Outsource (to a State-approved laboratory) select samples for chemical wastewater indicators, including caffeine, surfactants (methylene blue active substances), and/or fluorescent optical brighteners, and Phylochip analysis. Submit copies of data summaries to Grant Manager. *Completed and submitted to grant manager on 8/4/2011. Details are provided in the UCSB Final Report.*

5. Data Analysis.

5.1 Use vendor-supplied software to download data from field instruments. Process data according to QAPP. *Completed.*

5.2 Produce time series of flow and field data at each sampling location, and submit to Grant Manager. *Completed and submitted on 8/4/2011.*

5.3 Produce load calculations based on concentration and flow data at each sampling location. *This item was not completed because it did not support protocol development.*

5.4 Maintain ongoing correlation analysis among traditional and Deoxyribonucleic acid (DNA)-based indicators. *This correlation is maintained by Dr. Patricia Holden at UCSB.*

6. Modeling.

6.1 Develop GIS tools for visualizing and analyzing source tracking and sanitary survey investigation.

6.1.1 Submit summaries of GIS modeling results to Grant Manager. *Completed and submitted on 8/4/2011.*

7. Source Tracking Protocol Report for Coastal Managers.

7.1 Prepare a report for coastal managers that summarizes protocols tested, their efficacy, and provide case studies of the research conducted here. Prepare a supplement to the report that describes CCTV work. Submit report and report supplement to Grant Manager. *Completed and submitted on 5/24/2011.See Appendix A for report.*

**TABLE 6. ITEMS SUBMITTED FOR REVIEW**

| Item | DESCRIPTION |
|---|---|
| A. | PLANS AND COMPLIANCE REQUIREMENTS |
| 1. | GPS information for Project site and monitoring locations |
| 2. | Project Assessment and Evaluation Plan (PAEP) |
| | Non Point Source Pollution Reduction Project Follow-up Survey Form |
| 3. | Monitoring Plan (MP) |
| 4. | Quality Assurance Project Plan (QAPP) |
| 5. | Copy of final CEQA/NEPA Documentation |
| B. | WORK TO BE PERFORMED BY GRANTEE |
| 1.1 | Photo Documentation of Equipment Installation and Testing |
| 2.2 | Final Sampling Plans |
| 3.1 | Photo Documentation of Field Work |
| 3.2 | Copies of Field Notebooks |
| 4.1 | Laboratory Log Books of In-House Analyses |
| 4.2 | Data Summaries for Outsourced Analyses |
| 5.2 | Time Series of Flow and Field Data |
| 6.1.1 | Summaries of GIS Modeling Results (One or Two Pages) |
| 7.1 | Protocol Report for Coastal Managers |
| 7.2 | Supplement to Report for Coastal Managers |
| F. | REPORTS |
| 1. | Grant Summary Form |
| 2. | Progress Reports by the twentieth ($20^{th}$) of the month following the end of the calendar quarter (March, June, September, and December) |
| 3. | Annual Progress Summary |
| 4. | Natural Resource Projects Inventory (NRPI) Project Survey Form |
| 5. | Draft Project Report |
| 6. | Final Project Report (NOT YET SUBMITTED) |

## METHODOLOGY

The following methods were used in support of the Source Tracking Protocol Development Project. Methods are described in detail in the QAPP, including Standard Operating Procedures, the Monitoring Plan, the Final UCSB Report, and the Guide for Coastal Managers.

- Water Sampling (QAPP Section 11, 12, QAPP Appendix 1)
- Non-human Waste Specific Markers (QAPP Section 13, QAPP Appendices 2, 3, 5, 7, 9, 13; UCSB Final Report )
- Human-Waste Specific Markers (QAPP Appendices 4, 8, 10, 11, 12, UCSB Final Report )
- Bacterial Community Methods (QAPP Appendix 5, UCSB Final Report)
- Flow-Paced Sampling (UCSB Final Report )
- Autosamplers (UCSB Final Report)
- Flow Gauges (UCSB Final Report)
- Sanitary System Techniques in Storm Drains: Dye, Televising, Smoke Testing (Guide for Coastal Managers)
- Canine Scent Tracking (Guide for Coastal Managers)
- GIS – Mapping and Multi-parameter Water Indices (UCSB Final Report, Guide for Coastal Managers)
- GIS for Targeting Indirect Connections (UCSB Final Report, Guide for Coastal Managers)
- Dye Studies for Targeting Indirect Connections (UCSB Final Report, Guide for Coastal Managers)

## PUBLIC OUTREACH

Fromthe inception of the Source Tracking Protocol Development Project, the City of Santa Barbara has been committed to sharing results and techniques with other practictioners and the public. The avenues for dissemination have included:

> ***Coastal Managers Guide:*** The City synthesized results from the highly-technical UCSB Final Report and associated peer reviewed publications, along with City experiences and case studies from other communities to create a reader-friendly guide, “Tracking Human Fecal Pollution in Urban Storm Drains, Creeks, and Beaches.” The intent of this guide is to show other communities that there are indeed infrastructure problems that can lead to sewage contamination of coastal environments, and that tools do exist to evaluate problems and track their locations.

> *Creeks Advisory Committee: The* City of Santa Barbara’s Creeks Division is served by a Creeks Advisory Committee which has received regular updates on this grant project and its findings.

While the Committee has supported end-of-pipe treatment, including low-flow diversions and UV disinfection, members have consistently requested that the sources of contamination be investigated, even after project completion.

*Santa Barbara City Council Sustainability Committee:* The Creeks Division presented this project to the Sustainability Committee.

*Conferences:* The City of Santa Barbara presented results from this work at the following conferences:

- StormCon 2009, 2011
- UCSB Sustainability Summit, 2011
- Chesapeake Bay Storm Water Partners Retreat (Invited Speaker), 2012

*Presentation to Non-Governmental Organizations:* The City provided presentations to the Surfrider Foundation and the League of Women Voters.

*City TV:* The City of Santa Barbara's City TV broadcasts all Creeks Advisory Committee meetings and also created a segment on source tracking for Inside Santa Barbara.

*City of Santa Barbara Creeks Division E-News:* E-News carried a detailed feature about the Carrillo Drain leak, shown above.

## CONCLUSIONS

## PROJECT EVALUATION & EFFECTIVENESS – RESULTS OF PAEP

**TABLE 7. PROJECT ASSESSMENT AND EVALUATION PLAN TABLE**

| *Project Goals* | *Desired Outcomes* | *Output Indicators* | *Outcome Indicators* | *Measurement Tools and Methods* | *Targets* |
|---|---|---|---|---|---|
| *1. Develop protocols for source tracking of contamination that causes beach warnings.* | *1. Produce a report that contains pragmatic, accessible source-tracking protocols for identifying sources of indicator bacteria and markers for* | *1. Completeness of field sampling and modeling contained in research plan.*<br>*2. Completeness of documentation and reporting to ensure that results accessible.* | *1. Improvement in City's capacity to track contamination problems to the source upon consistently high indicator bacteria levels during AB411 dates.*<br>*2. Improvement in Statewide capacity to track contamination problems to the source upon consistently high* | *Sample protocol guidelines: Delivering Timely Water QualityInformation to Your Community: http://www.epa.gov/nrmrl/pubs/625r03002/625r03002.pdf* | *Broad distribution of protocol development based on City's use of protocols and dissemination to other municipalities and the State Board.* |

| | | | | | |
|---|---|---|---|---|---|
| | *human waste to storm drains..* | | *indicator bacteria levels during AB411 dates.* | | |
| *2. Identify source(s) of contamination (indicator bacteria and human waste markers) coming from storm drain outlets to Mission Creek.* | *1. Identification of source(s) of indicator bacteria and human waste entering key storm drains.* | *1. Completeness of investigation, including field work, sampling, and modeling, on diffuse transport from sewer line to storm drain system.*<br>*2. Completeness of investigation on pulsed flow in storm drains from sump discharges.*<br>*3. Completeness of investigation in surrounding neighborhoods during study periods.* | *1. Percent of source identification for contamination discharged from key storm drains.* | *ADS Environmental Services. 2003. Santa Barbara Wastewater Collection System Infiltration & Inflow Study-2003.*<br>*City of Santa Barbara. 2002. Stormwater treatment options for reducing bacteria in Arroyo Burro and Mission Creek watersheds*<br>*City of Santa Barbara. 2000. Storm Drain Atlas.* | *1. Identification of physical source responsible 50% or more of indicator bacteria and human waste markers coming from key storm drains. Attribute remaining 50% of load to non-point-sources in specific reaches of storm drains.* |

## PROJECT GOAL 1: DEVELOP SOURCE TRACKING PROTOCOLS

### DEVELOP PROTOCOLS FOR SOURCE TRACKING OF CONTAMINATION THAT CAUSES BEACH WARNINGS.

This goal was fully met by reaching the desired outcome, i.e., the production of report with pragmatic, accessible tracking protocols for identifying sources of indicator bacteria and markers for human waste in storm drains. The outcome indicators were both met. First, the City of Santa Barbara's capacity to track contamination problems to their sources has improved dramatically. These tools will be used whenever consistently high indicator bacteria levels are measured at beaches in the City during AB411 dates (the City also tracks upstream in dry winter weather). Second, the distribution of the techniques and approaches via conference proceedings, peer-reviewed articles, and the report "Tracking Human Fecal Pollution in Urban Storm Drains, Creeks, and Beaches " has already led other communities to utilize some of the tools. The State Water Resources Control Board's Clean Beaches Initiative Source Identification Protocol Project has also drawn on the results of the Source Tracking Protocol Project. The measurement tool was an existing report for a protocol guide for a different type of water quality testing. The example report, <u>Delivering Timely Water Quality Information to Your Community</u> (US EPA, 2003) is approximately 100 pages and set out to introduce people to the idea of basics of water quality monitoring and provide sufficient detail to guide program development. We decided for this project that two reports would better reach our intended audience – a short and photo-rich report that would entice communities to tackle human waste issues and a complementary highly technical report with detailed protocols for communities to utilize during planning an interpretation. The Target from the PAEP is broad distribution of the Coastal Managers Guide ("Tracking Human Fecal Pollution in Urban Storm Drains, Creeks, and Beaches"). This will be accomplished by posting the reports on the City's and State Board's websites, along with sending email notifications via the State Water Resources Control Board's listserves and the NPSInfo listserv.

At many locations, total maximum daily load (TMDL) criteria have been developed for fecal indicator bacteria in order to lower their levels, but in most cases the implementation plans do not distinguish among sources of indicator bacteria. While eliminating all fecal indicator bacteria may lead to fewer beach warnings, it can be an impractical or impossible task in many locations. Once human waste has been identified in recreational waters, it is imperative to track contamination upstream in order to eliminate or reduce the input.

### Project Goal 2: Identify Sources of Contamination

#### Identify source(s) of contamination (indicator bacteria and human waste markers) coming from storm drain outlets to Mission Creek

This goal was largely met by the Project. Two grant agreement amendments led to a change of scope, which narrowed the focus of the project to develop tools or tracking human waste rather than the broader class of indicator bacteria. This change was made after direct sewage connections to the storm drain network were found. The desired outcome was the identification of source(s) of indicator bacteria and human waste entering key storm drains. In storm drains where signals of human waste were found consistently, sources of human waste were located. One of the key storm drains targeted at the onset of the project, the Haley Drain, had shown consistent and, at times, high concentrations of human waste markers over several years. However, when the same drain was sampled for this project, the results came back negative for human waste markers. Sources of indicator bacteria were not related to human waste, and their origins were not pursued during the remainder of the Project period.

The output indicators were fully reached. First, the completeness of investigation, including field work, sampling, and modeling, on diffuse transport from sewer line to storm drain system was 100%. Second, the completeness of investigation on pulsed flow in storm drains from sump discharges was 100%. Third, the completeness of investigation in surrounding neighborhoods during study periods was 100%. The outcome indicator, percent of source identification for contamination discharged from key storm drains will not be determined until follow up testing for human waste markers is complete, which the City intends to perform once all sewer pipe repairs have been completed.

The measurement tools, which included three reports, were all used successfully during the project. The target, identification of physical source responsible 50% or more of indicator bacteria and human waste markers coming from key storm drains, was difficult to measure in most locations. At the onset of the project, it was expected that indicator bacteria and human waste markers would correlate well enough to compare and subtract loads of each indicator. In actuality, the measures are all highly variable, and do not necessarily correlate. In one case, the Carrillo Street Storm Drain, where the entirety of dry weather flow was found to be comprised of sewage, repairs to the pipes resulted in 100% of the loads of human waste markers and indicator bacteria being sourced and eliminated. At the Hope Drain, a source of sewage was eliminated, resulting in negative results for human waste markers in later testing. However, indicator bacteria concentrations remain high (data not included in this Project).

## Lesson Learned

Identify lessons learned in carrying out the Project. Describe what worked and what did not work, and how similar efforts could be utilized within the Project area, as well as in other watersheds.

1. Work with specific with ***specific questions and hypotheses***, rather than a shot-gun approach. Sample methods are too expensive, and the results too variable, to expect a broad-brush approach to help resolve contamination questions. More than likely, you have monitoring data from having sampled creek or beach water, and having analyzed for fecal indicator bacteria. All these data, including their amounts at various locations and times, shown in a graph and analyzed with simple statistics, to drive where you prioritize your next sampling efforts towards source identification.
2. Do not expect a single method to provide all of the answers. A ***toolbox approach*** is necessary for tracking human waste contamination.
3. Try to sample in places and times that represent ***"worst-case scenarios."*** This way, if results come back negative for human-specific waste markers, it is more likely that contamination problems do not truly exist.
4. ***Consistent positive results for human waste markers***, even at low concentrations, likely signal a sustained input to the storm drain. Moving up a storm drain is best pursued with camera and/or dye studies. On the other hand, recognize that marker concentrations will vary, especially where additional water inputs arise and cause marker dilution.
5. Seek grant funding and ***partnerships with university researchers.***
6. Expect "messy" results, and ***be persistent***.

**TABLE 8. TOOLS FOR TRACKING HUMAN FECAL CONTAMINATION IN STORM DRAINS.**

| TOOL | BEST USE | CAVEATS and CHALLENGES | COSTS | AVAILABILITY |
|---|---|---|---|---|
| **Human-specific waste markers** | Best tool for quantifying inputs of human waste. Best for sampling in creeks, beaches, storm drain outfalls or major nodes in storm drain network. | Plan repeated sampling to account for variable results.Different results for urine-specific vs. fecal-specific waste markers may indicate different sources of input. | $$$ | ## |
| **Community approach, e.g. Phylochip** | Best for sampling along a gradient of suspected inputs, e.g. to test if septage is entering a creek. May be advantageous in storm drains diluted with clean ground water, | At this point, results are not conducive to simple interpretation suitable for a nontechnical audience. Contact Second Genome, Inc. | $$$ | ### |

| | | | | |
|---|---|---|---|---|
| | due to low detection thresholds. | http://www.secondgenome.com/tag/phylochip/) | | |
| **Flow gauges and autosamplers** | Best for drains with evidence of higher flows (wet walls, signs of water shooting into creek channel).Excellent for estimating loads of fecal pollution. | Check specs carefully to find flow gauges suitable for dry weather flows. Requires confined space entry in most cases. | $$$ (one time) | # |
| **Non Human-Specific Chemistry** | Finding illicit connections besides sewage leaks. Good for understanding nutrient inputs from any type of illicit connection. | Background signal of urban runoff can make fingerprinting sewage difficult. | $$ | # |
| **Canine Scent Tracking** | Best for use when real time results are desired, such as working up storm drain networks with many branches. | Canines may respond to non-human illicit connections, due to training with detergents. Contact Environmental Canine Services (http://www.ecsk9s.com/). | $$ | ### |
| **CCTV** | Best for use where sampling data suggests sustained input of sewage. | Most operators are trained for sanitary sewer pipe inspection, and may seek to clean the lines first. Plan to guide operators to slow down, look carefully at leaks, and do not clean the lines first (in order to see solids on bottom of storm drain). | $$ | ## |
| **Basic Dye Test** | Best for testing laterals or fixtures feeding a single illicit connection that has been observed in CCTV work. | Use bright green dye and a UV light to look for dye in storm drains. | $ | # |
| **Smoke Test** | Best for limited geographic areas with strong evidence for direct connections, e.g. visible toilet paper. | Difficult in large pipes and densely populated areas. | $$ | # |
| **Dye with Rhodamine Probe** | Best for testing suspected sewage infiltration to storm drains, when persistent human-waste markers are found without observing solids such as toilet paper. | Difficult to know how long to leave probe in storm drain. Rain events may create a false positive signal. | $$ | ## |
| **GIS** | Essential for planning and analyzing data in relation to infrastructure. | | $$ | ## |

## NEXT STEPS

The next steps for the City of Santa Barbara are to rehabilitate and replace sanitary sewer pipe segments based on priorities generated by this project. The City entered a legal settlement with Santa Barbara ChannelKeeper to increase the rate of rehabilitation and replacement, among other tasks, for the next five years. The City recently proposed and passed an increase in sewer rates to fund the increased replacement.

In spring 2013, the City will conduct additional sampling for human waste markers at downstream locations in spring 2013, after winter rains have flushed any relic signals from storm drains. It is expected that emergency repairs made during this project, along with rehab and repair, will lead to very few positive results for human waste markers in the Laguna, Mission, and Arroyo Burro Watersheds.

The City is also conducting more extensive surveillance of potential RV dumping into storm drains than it has conducted previously. An estimate of RVs parking overnight on City streets and in Safe Parking Lots will be compared to the number of RVs that dump waste tanks (at no cost to the RV owner) at the Marborg Waste Facility in Santa Barbara. Previous results using canine scent tracking and a log of enforcement calls do not suggest a large problem with dumping, but the City is taking extra steps to confirm this result.

## REFERENCES

Note that extensive references are provided in each chapter of the UCSB Final Report (Appendix B)

Rieckermann, J., M. Borsuk, P. Reichert, and W. Gujer. 2005. A novel tracer method for estimating sewer exfiltration. Water Resources Research 41.

Sercu, Bram B.S., LC Van De Werfhorst, J.L.S. Murray and P.S. Holden. 2009. Storm drains are sources of human fecal pollution during dry weather in three urban southern California watersheds. Environ. Sci. Technol. 43(2):293-8.

USEPA. 2000. Exfiltration in Sewer Systems. Accessed online on 8/16/2012 at: nepis.epa.gov/Adobe/PDF/2000E6PB.pdf

US EPA. 2011. Report of the Experts Scientific Workshop on Potential Human Health Risk from Exposure to Fecal Contamination from Avian and Other Wildlife Sources in Recreational Waters. Accessed online on 8/16/2012 at: water.epa.gov/scitech/swguidance/standards/criteria/health/recreation/upload/avian_report.pdf

## *Appendix A: Guide For Coastal Managers*

### *"Tracking Human Fecal Pollution in Urban Storm Drains, Creeks, and Beaches"*

## ***Appendix B UCSB Final Report***

## ***Appendix C: Comprehensive Televising and Dye Studies of Target Storm Drains***

## *Appendix D: Canine Scent Tracking*

## *Appendix E: Peer Reviewed Articles*